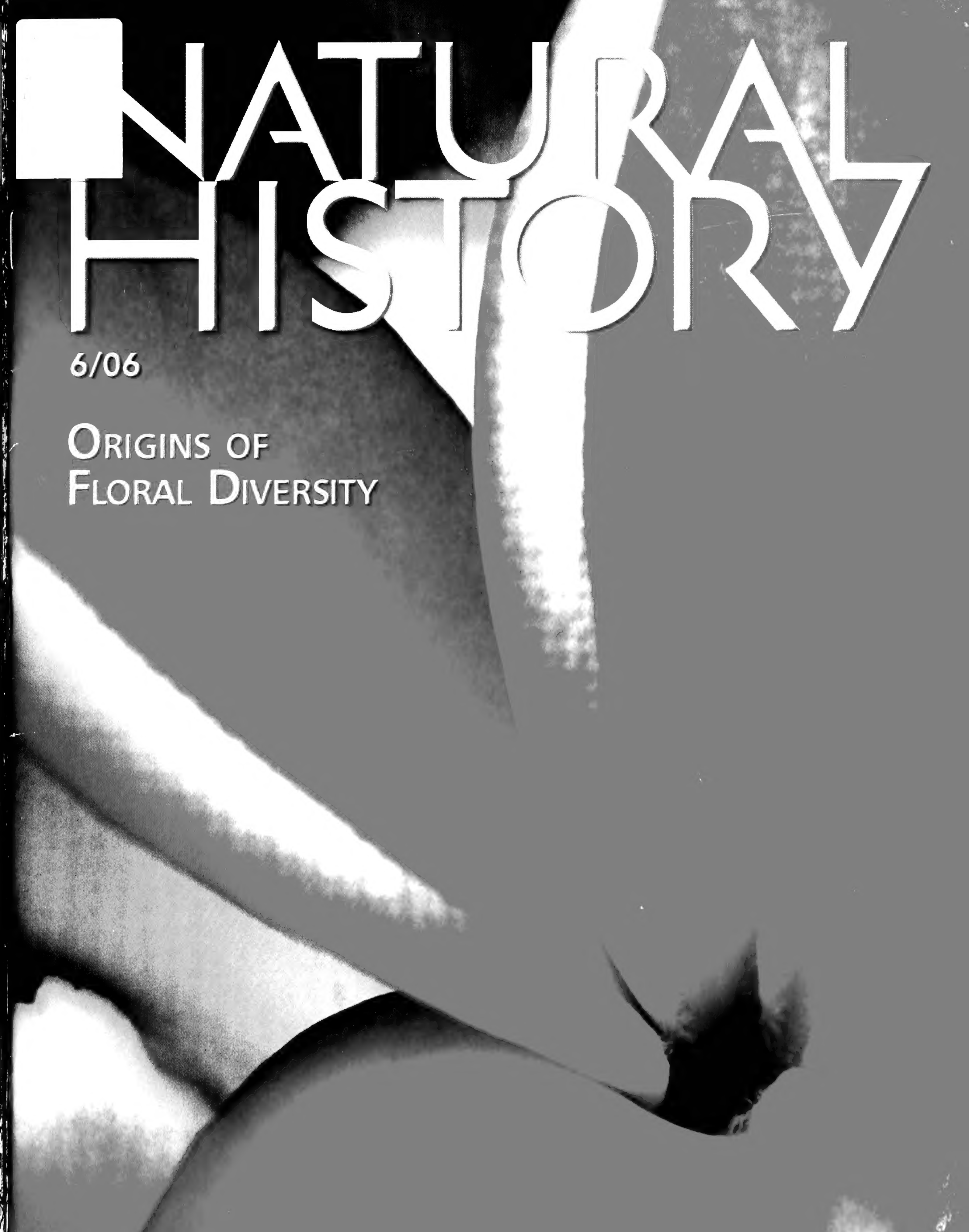
NATURAL HISTORY

6/06

ORIGINS OF FLORAL DIVERSITY



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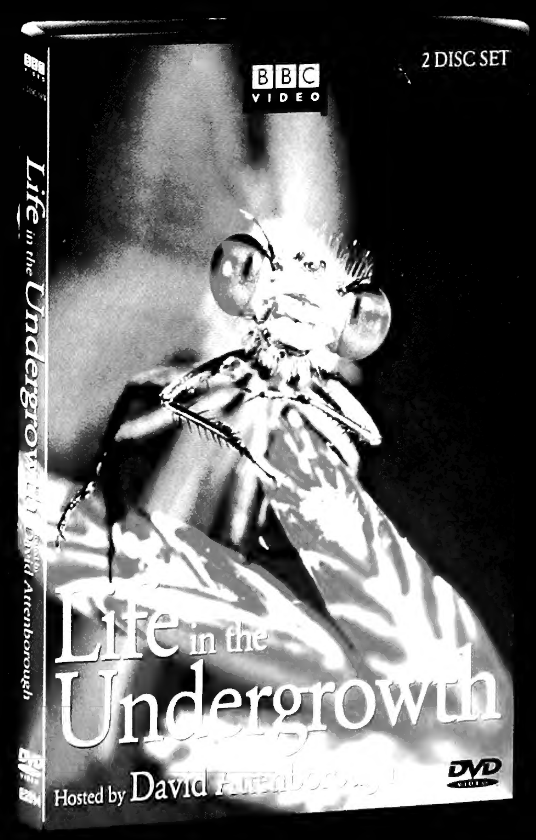

BBC VIDEO

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NATURAL HISTORY

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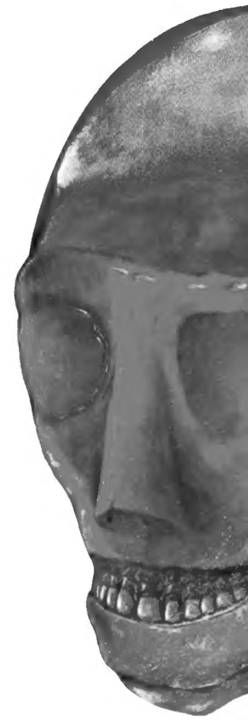

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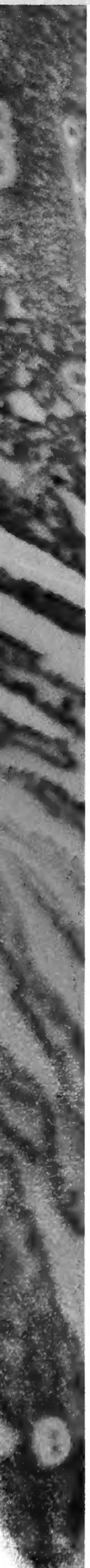

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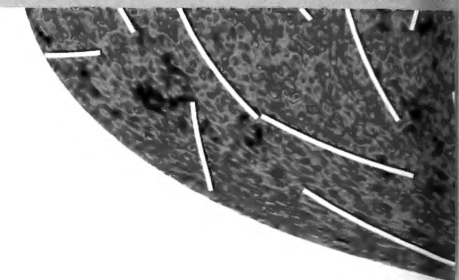

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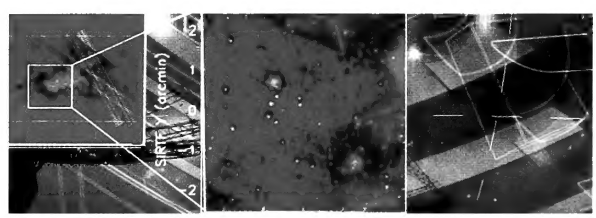

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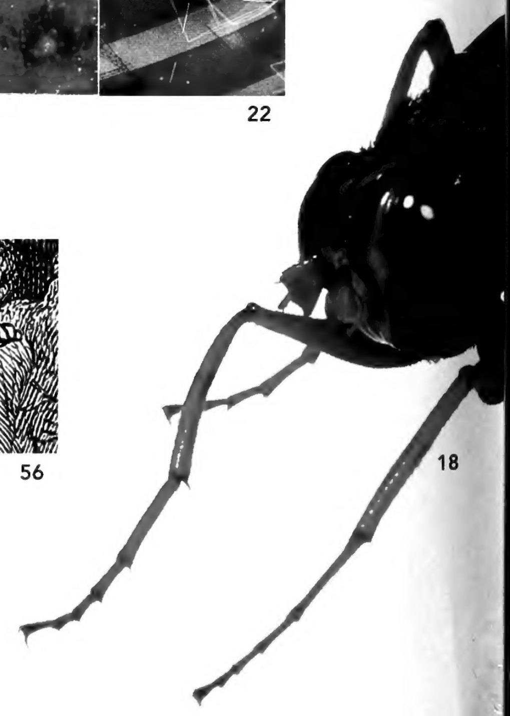

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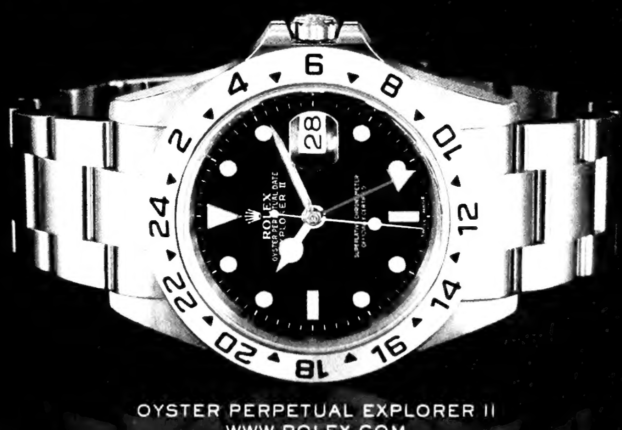
On February 3rd, 2006, Rune Gjeldnes arrived in Victoria Land, finishing his conquest of skiing solo across Antarctica, from Queen Maud Land via the South Pole. After traversing 4,804 kilometers of the Earth's most inhospitable landscapes, he became the world's first explorer to cross Greenland lengthways, the North Pole ice cap and Antarctica on skis unaided. Congratulations, Rune. The world is yours, from top to bottom.



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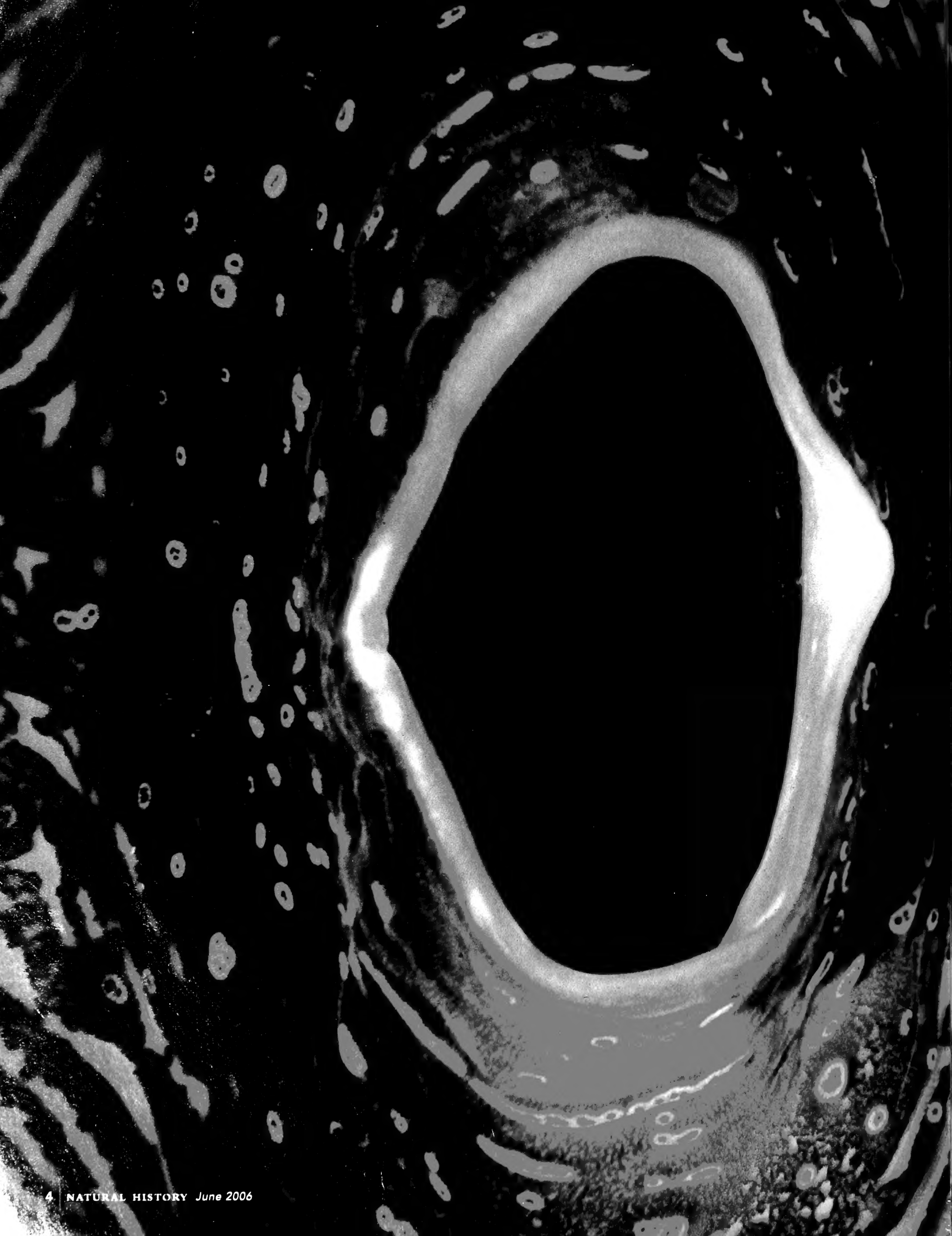
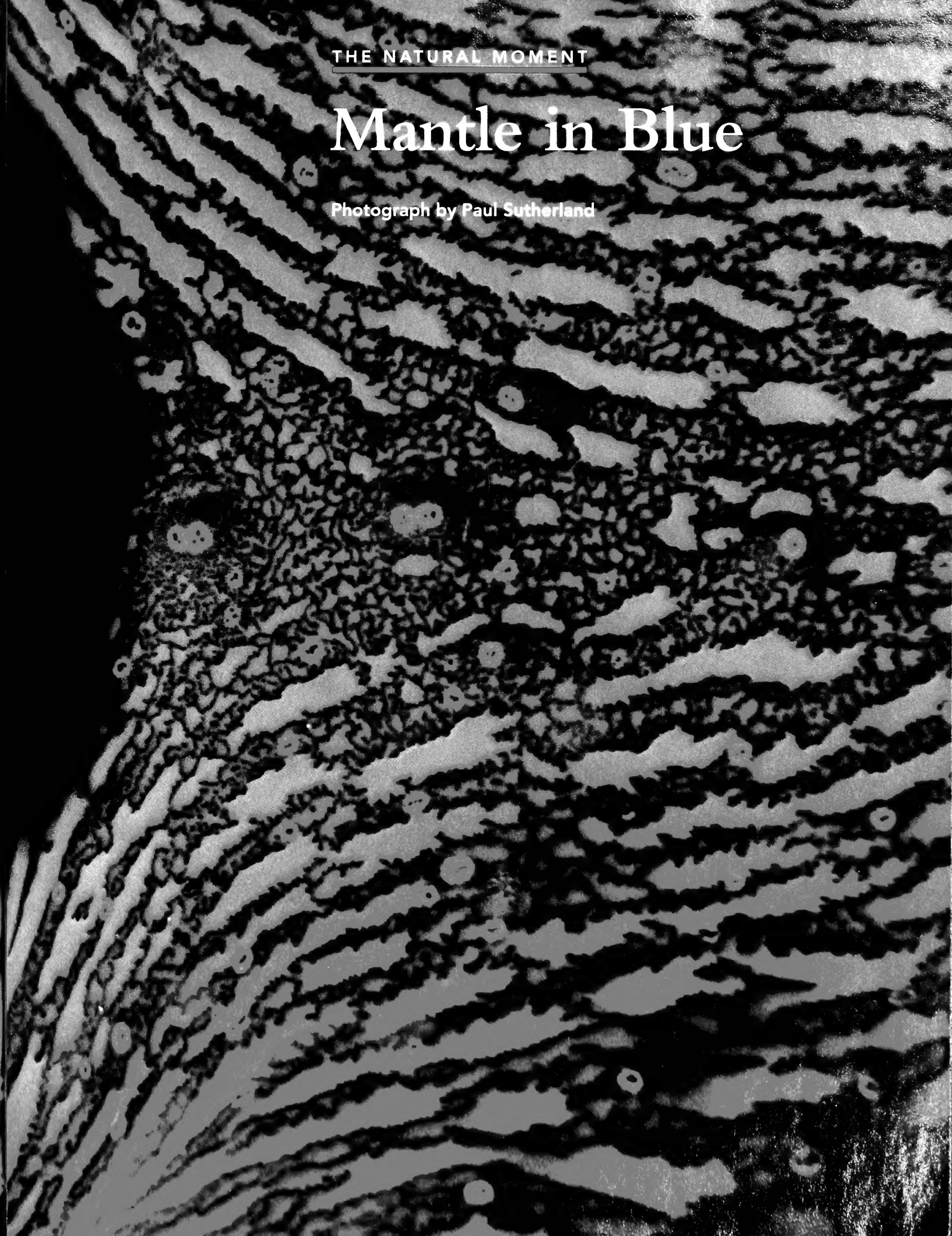


Mantle in Blue

Photograph by Paul Sutherland



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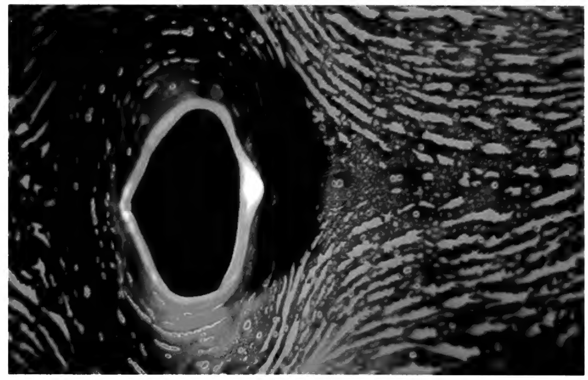
THE NATURAL MOMENT

◄ *See preceding two pages*



Hover over the maw of a giant clam and you'll be mesmerized by the life between its shells—far more stunning than any bubbling mermaid. Intense, kaleidoscopic colors are swirled and stippled into patterns that recall the adage about snowflakes: no two are ever alike. The colorful sheath of tissue, appropriately dubbed a mantle, spans the two scalloped shells that it accretes; the shells of some species can exceed four feet in length and several hundred pounds in heft. Truly, they are the behemoths of the bivalves.

Giant clams (in the subfamily Tridacninae) take years to reach elephantine status, growing throughout a lifetime that sometimes lasts a century. The juvenile pictured here measured only about eight inches across. Photographer Paul Sutherland spied the blue beauty in shallow waters around Layang Layang, an atoll ninety miles from Borneo in the South China Sea. Finding large specimens there or anywhere else has become a challenge, because of overfishing and shrinking habitats.

Entranced, Sutherland zoomed in on the muscular hole where the clam spews out wastewater: a second anus, you might say. Clams filter-feed by siphoning in surrounding water, raking what they want through their gills, and pumping out the leftovers. Given the blimplike size of species such as *Tridacna gigas*, which is the largest of them all, the clams have the power to siphon loads of water quickly—enough to collect plenty of food themselves. But, in the marine world, extra bulk can offer valuable real estate for ready profit. Giant clams lease their personal space and increase their food consumption by taking in algae as tenant farmers. The algae, known as zooxanthellae, live by the millions inside the clams, where they actually provide most of the clams' nutrients.

To produce energy for themselves and for the clams, algae need intense sunlight. So, as a precaution for the clam, evolution has ensured that pigments screen out ultraviolet rays—which, it turns out, accounts for much of the color variation on the creature's fleshy surface. The clams keep their end of the symbiotic bargain by keeping a few "windows" clear of pigment, finding a permanent spot near the surface, and staying open during daylight hours—all to let in some light. (They can still exercise ownership control on the algal population, often digesting or expelling any unwanted tenants.) But, because the clams' only means of defense is shutting themselves inside their tough shells, staying open leaves the clams vulnerable to attack.

So, what tells them when to clam up? Motion sensors, for one. Plus the giant clams have eyes—hundreds of rudimentary retinas that rim their mantles. Sutherland was undoubtedly spotted by the eyespots on his subject: the clam winked shut several times as he swam above it. —*Erin Espelie*

What was Canon thinking when they developed a digital SLR with the personality of a film camera?

"Exactly what I was thinking."

George Lepp If you're like me, you love the freedom and creative advantages that digital affords. But you don't want to give up the nuances of film. That's why I find the EOS 5D such an incredible camera. It's got a full-frame CMOS sensor–exactly the same size as a 35mm frame, so I not only get huge files with incredible detail, but the full-frame sensor lets me compose my shots without a lens conversion factor. And because it's so small and light, it's the perfect companion for those long treks into the wild. It's really no surprise that Canon is the only maker of a 35mm full-frame D-SLR. After all, they're the guys who listen.

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Say It with Flowers

Nature has been perfecting the sensual attractions of flowers for millions of years. Yet what blossoms so poignantly express to us is not longevity, but transience: enjoy them today, for tomorrow their petals will litter the ground. How apt that June, a season silly with flowers, is the month traditionally chosen for some of life's happiest milestones—the graduations, the weddings, days some of us plan for years. Savor the moment, say the flowers of June. This year our daughter Julia is a June graduate, and my wife and I will be among the beaming parents. It wouldn't surprise me if Julia made her appearance in robe and mortarboard with a rose tucked rakishly in her hair.

There is another response to floral profusion—equally valid, and felt with equal passion—which Amy Litt articulates in her cover story, "Origins of Floral Diversity" (page 34). "Most people are content to take pleasure in the sheer abundance and variety" of flowers, she writes. "We evolutionary botanists are less easily gratified." And when you think about it, the cultural tradition that says blossoms are ephemeral gets at only part of the truth about nature's floral extravagance. Biologically, there's nothing ephemeral about it. Millions of years of evolutionary warfare have led to highly efficient devices coldly calibrated to get the mobile pollinators of the world to propagate the rooted species. And—fair warning—Litt has not shrunk from describing the genetic jigsaw puzzle that underlies the astonishing diversity of floral forms.

• • •

Jane Jacobs, the critic and tireless advocate for the benefits of urban life on a human scale, died this past April. With her in mind, here's another puzzle posed by a story in this issue, for anyone fascinated by the idea of a city. What "city" never really became a city? Where did people live together at high densities for more than a thousand years without forming a centralized community structure? The answers to those questions are coming into focus at an archaeological site in central Turkey known as Çatalhöyük (see Ian Hodder, "This Old House," page 42).

High-density living in Çatalhöyük seems to have been a stew of unimaginable pungency. Families built their houses cheek by jowl, on top of the homes of their ancestors. They buried their dead under raised platforms in their main living quarters, and tossed garbage and human waste in the gap between their own outside walls and those of their neighbors. No wonder, as Hodder notes, they reached their rooms by climbing over their neighbors' roofs and down a flight of stairs! Yet despite the high density, few signs of any common area, village government, or even shared production of goods were part of life in Çatalhöyük.

The excavation of Çatalhöyük has been going on, in fits and starts, for more than forty years, yet archaeologists have, almost literally, only scratched the surface of what it has to say about the varieties of the human condition.

—PETER BROWN

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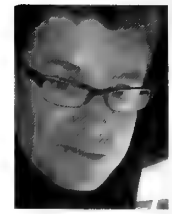

Last year, photographer **PAUL SUTHERLAND** was suspended from the stern of a fishing boat making eight knots as it laid out a longline; he was attempting to capture midair shots of albatrosses and petrels scavenging the boat's discarded fish. For Sutherland, that's all in a day's work, as he documents life in and around the water. His mesmerizing underwater close-up of a giant clam ("The Natural Moment," page 4) could be a piece of abstract art—so exotic is the clam's skin and siphon hole to most of us. Sutherland's work has been published in *National Geographic, Nature Australia, Scientific American,* and *U.S. News & World Report.* More of his photographs appear online (www.sutherlandstock.com).

AMY LITT ("Origins of Floral Diversity," page 34) did not follow a straight path to her current position as director of the plant genomics program at the New York Botanical Garden (NYBG). After earning her master's degree in biology, she taught middle-school and high school science for a number of years. An eco-tourism excursion in the Amazon rainforest introduced her to the extraordinary diversity of flower forms and lured her back to academia. Litt earned her doctorate from the City University of New York, concentrating in floral structure. At NYBG Litt applies genomic and molecular techniques to study the evolution of forms in flowers and fruits.

Since 1993, archaeologist **IAN HODDER** ("This Old House," page 42) has been leading the excavation of Çatalhöyük, a 9,000-year-old Neolithic site in central Turkey. The project aims to place the abundant art from the site in its full economic, environmental, and social context; to conserve the paintings, plasters, and mud walls; and to present the site to the public. Further information and images about the site are available on the Web (www.catalhoyuk.com). Hodder is currently the Dunlevie Family Professor in the department of cultural and social anthropology at Stanford University. His article in this issue has been adapted from his forthcoming book, *The Leopard's Tale: Revealing the Mysteries of Çatalhöyük,* which is being published this month by Thames & Hudson.

While still a graduate student at the University of Buenos Aires, **GRACIELA FLORES** ("Good Fences, Good Neighbors?" page 48) realized she wanted to broaden her view of the life sciences. After earning a doctorate in biology, Flores left research to pursue a career in teaching and writing. She has designed biology courses for high school teachers and co-authored two college-level biology textbooks. Now an editor-at-large at *Natural History,* Flores also freelances for the Reuters news agency and publications such as *The Scientist,* writing about health, research, and technology.

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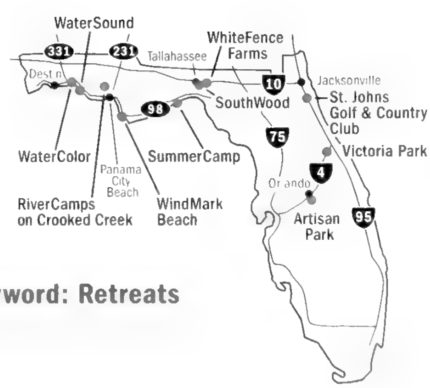

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Swimming with Sharks

Steven G. Wilson's informative overview of the whale shark ["The Biggest Fish, 4/06] points out the little we know, and the lot we don't know, about the largest of all fishes. Mr. Wilson notes that the animal is threatened by fishing and boat strikes, but those who would protect the whale shark must also be alert to the potential for harmful effects from the growth of whale-shark ecotourism. For example, the thousands of people who now swim with whale sharks could end up driving them away from their feeding grounds if the practice isn't studied and regulated.

Because whale sharks range so widely, regional studies of them are limited. What is needed, if we are to avoid losing these magnificent animals from the planet, is an integrated, global study of the species.

Robert E. Hueter
Mote Marine Laboratory
Sarasota, Florida

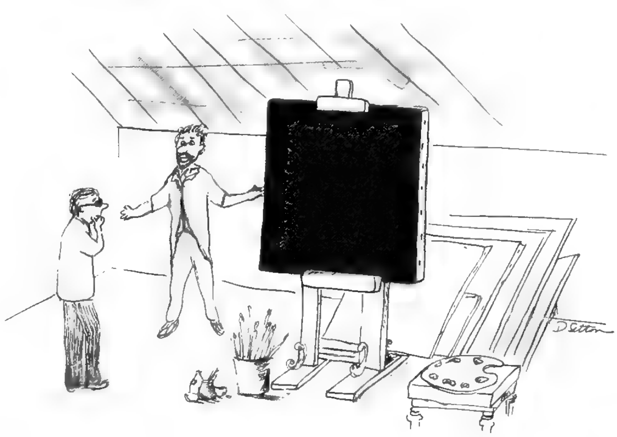
Steven Wilson's article prompts me to ask a question I've always wondered about: Couldn't a person be sucked in by a whale shark and become pinned to its gills?

Richard W. Crews
Encinitas, California

STEVEN G. WILSON REPLIES: Robert E. Hueter raises excellent points about ecotourism. To avoid or mitigate the problem, authorities in Western Australia have developed stringent guidelines for managing human activities around whale sharks.

Beyond limiting or banning their harvest and redirecting communities to the regulated and nonconsumptive use of whale sharks, we need to study the movement patterns of the species and the oceanographic factors that control them. Such work is critical if we are to conserve and manage whale shark populations and understand longer-term threats such as those posed by global climate change.

I think the fear expressed by Richard W. Crews crosses the mind of anyone who swims with a whale shark. Although a person would certainly fit inside the mouth of the adult animal, I have never heard any report of such an accident. A whale shark would probably avoid ingesting an object as large as a person; in fact, when a person swims just in front of a whale shark, the animal usually responds by closing its mouth or altering its course.



"I call it 'Astronomy Beyond the Visible-light Spectrum.'"

Love Those Dioramas!

Although the panorama, diorama, and cyclorama were critical to the development of the museum-habitat diorama, as described by Stephen Christopher Quinn in his article, "The Worlds Behind the Glass" [4/06], emphasis needs be put on the cyclorama of the 1880s. "Cyclorama" was the name frequently given to a form of the panorama, a borderless painting arranged in a circle to mimic the impression of a view seen completely around. The cyclorama embellished the illusion with faux terrain, or artificial figures and objects, which were added both in front of the picture and blended in to it—precisely the "tie-in" of three-dimensional foreground with painted and curved background that Mr. Quinn describes in his article. In a remarkably propitious alignment of circumstances, nineteenth-century advances in both taxidermy and pictorial entertainment converged in the 1880s to inform the museum dioramas that still delight and instruct us today.

Kevin J. Avery
The Metropolitan Museum of Art
New York, New York

Before we met, both my wife and I often visited the American Museum of Natural History in New York City. My favorite area was the Akeley Hall of African Mammals. This past March we visited New York for the first time in thirty years. Naturally, our first stop was the American Museum. Akeley Hall was just as I remembered it—awesome! On returning home, we found the latest issue of *Natural History,* with Stephen Christopher Quinn's article. It brought back memories both distant and current.

Al Westerfield
Crossville, Tennessee

Worse than Fallout?

Mary Mycio's Endpaper "Chernobyl Paradox" [4/06] should have been your lead article. People have been destroying the natural world for eons, but showing so clearly and on such a grand scale that the human presence is so much worse than even the radioactive isotopes cesium-137 and strontium-90 should be a clincher in any environmental debate. Each new suburb, mall, and parking lot is more damaging to our world than the worst nuclear meltdown in history.

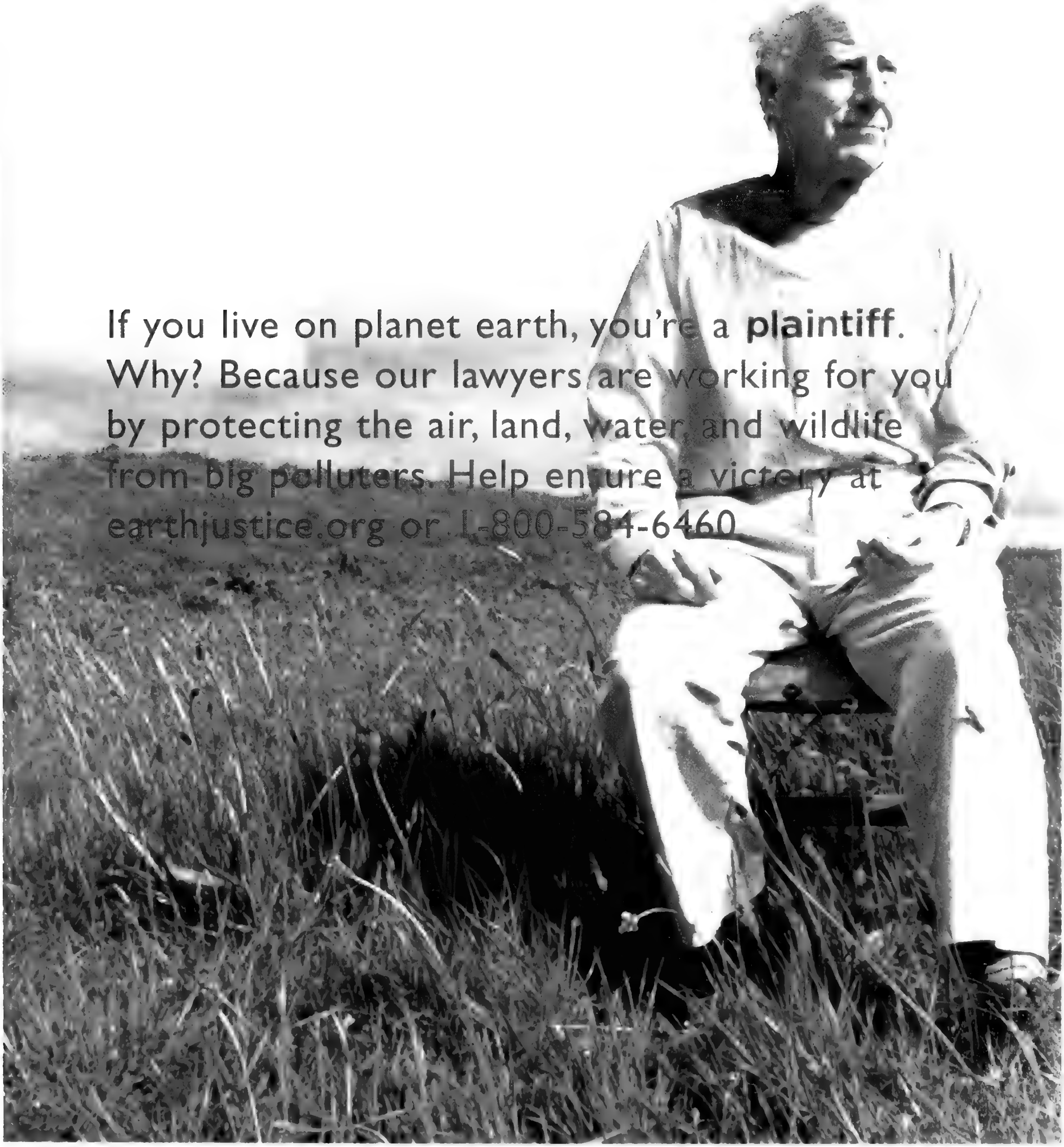
Richard S. Blake
East Falmouth, Massachusetts

Underground Heroes

Soil bacteria and fungi are the mechanistic workhorses that drive nutrient cycling in diverse terrestrial and aquatic ecosystems.

(Continued on page 60)

EARTHJUSTICE
Because the earth needs a good lawyer



Alaskan glacier is on the move.

Icequake

A global network of seismometers constantly monitors the Earth's rumbles and grumbles. Three years ago Göran Ekström, a geophysicist at Harvard University, noticed some unusual, low-frequency seismic waves, which looked nothing like the signals of moving tectonic plates. The strange waves, he discovered, originated in Alaska, Antarctica, and Greenland, where massive glaciers were lurching downslope, then stopping abruptly, shaking the earth below.

Once they identified the source, Ekström and two colleagues combed through seismographic records from 1993 through 2005, and picked 136 of the best-recorded "glacial earthquakes" originating at the edge of the Greenland ice sheet. The investigators found that those quakes took place most frequently in the late summer months. Presumably, that's when the most meltwater trickles down to the bases of the glaciers, reducing the friction between ice and ground and easing the glaciers along. And glacial earthquakes are on the rise. In 2005 there were twice as many quakes in Greenland as in any year before 2002. Glacial meltwater seems to be flowing freely these days, yet another sign of the warming climate. (*Science* **311:** 1756–8, 2006)

—Stéphan Reebs

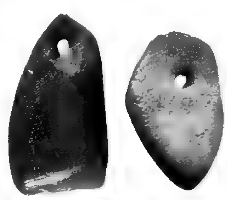
Gender Bias

Hypoxia, or oxygen scarcity, is accelerating across vast reaches of the world's waters. The cause is often pollution, and by now as many as 400,000 square miles of ocean are permanently hypoxic. In such areas, fish populations plummet. Some fish species simply drop dead from too little oxygen. But a new study suggests that low oxygen levels may also alter the sex ratios among fish populations, thereby compromising their survival.

Eva H. H. Shang and Rudolf S. S. Wu, both ecotoxicologists at the City University of Hong Kong, and a colleague compared zebra fish reared in tanks under hypoxic conditions with a control group raised in normally oxygenated water. After four months, the investigators discovered that many more males than females developed in the hypoxic tanks—74 percent of the population compared to 62 percent in "normoxic" tanks. They blame the imbalance on an altered ratio of two sex hormones at a stage in development when the fishes' gender is determined. Female fish reared in hypoxic tanks produced more testosterone and less estradiol than did fish reared in normoxic tanks. The cause, Shang and Wu found, was changes in the expression of genes that manufacture the sex hormones. The changes in hormone levels likely inhibit the development of female reproductive organs and other sexual traits and encourage male organs and sexual traits to develop instead. Fish with girl genes, it seems, grow up with boy bodies.

Shang and Wu suspect that even if fully female fish do manage to survive in hypoxic environments, they may produce fewer, poorer-quality eggs than normal. Because a fish population's reproductive success is limited by the number and fecundity of its females, Shang and Wu worry that hypoxia may be even more harmful to the world's fishes than previously thought. (*Environmental Science & Technology,* doi:10.1021/es522579, 2006) *—Rebecca Kessler*

Europe's First Fashionistas



The first anatomically modern humans to colonize Europe forged what archaeologists now call the Aurignacian culture, which persisted throughout Europe between 37,000 and 28,000 years ago. Over such a long time and wide area, it seems plausible that the Aurignacians spawned various subcultures and languages. Until now, though, regional differences among Aurignacian artifacts have been hard to identify.

Early European bijoux

Recently, however, the archaeologists Marian Vanhaeren of the University of Paris X and Francesco d'Errico of the University of Bordeaux I, both in France, have distinguished three broad geographical regions in the distribution of the Aurignacians' ornamental beads and pendants. The ornaments were usually shells, teeth, or bones, perforated or grooved to accommodate a cord. In parts of present-day Belgium and Germany, perforated teeth and tear- or disk-shaped ivory beads were more fashionable than elsewhere. In parts of Austria, southeastern France, Greece, and Italy, shells tended to be de rigueur. The mix of ornaments from Spain and from southern and western France is intermediate between the other two regions. Because the same raw materials were available everywhere, Vanhaeren and d'Errico argue that such fashion trends reflect cultural—and perhaps even linguistic—differences, and that the first Europeans were a diverse bunch. (*Journal of Archaeological Science*, in press, 2006)

—S.R.

Keep looking up: Australian lace monitor perches in a stringybark eucalyptus tree.

One Big Toxic Family

What makes the bite of the Komodo dragon a wound that can kill? Most biologists would point to the bacterial infection it causes. According to a new study, however, there may be a better explanation: venom. Fourteen scientists from six nations, led by Bryan G. Fry, a biochemist at the University of Melbourne in Australia, discovered that iguanas and monitor lizards (the group to which Komodos belong) have venom glands in their mouths. The investigators found that, in rats, the venom of the lace monitor, an Australian cousin of the Indonesian dragon, reduced blood pressure and clotting. Both effects would be handy for inducing loss of consciousness and extensive bleeding in prey.

Among reptiles, only snakes and two lizards—the Gila monster and its close relative, the beaded lizard—were previously known to possess venom. Its rarity in lizards had led biologists to think venom evolved independently in snakes and lizards. But the discovery of venom glands in iguanas and monitor lizards—along with the genes necessary for making at least nine different toxins that are shared by snakes—has forced a reevaluation of the reptiles' evolutionary history. Fry and his colleagues say that a system for venom production and delivery probably evolved just once, in an ancestor common to all venomous reptiles. The system evolved 200 million years ago—just when bite-size mammals were diversifying and spreading. (*Nature* **439:** 584–8, 2006) —*S.R.*

Is There a Doctor in the Barn?

All animals get sick from time to time, but most of them can't just reach for the aspirin. Anecdotes of nonhuman species that seem to self-medicate abound, but few have been experimentally corroborated. Now a study of domestic sheep shows that their pharmaceutical skills are surprisingly sophisticated.

Juan J. Villalba, an animal behavior specialist at Utah State University in Logan, and two colleagues conditioned four-to-five-month-old lambs to eat barley grain and food laced with tannins or oxalic acid. Each food gave the lambs some temporary discomfort: barley grain causes heartburn, tannins cause indigestion, and oxalic acid causes low energy and shortness of breath. After they were accustomed to eating each of the three foods, the test lambs were conditioned to consume the medicine appropriate to each food. (A control group of lambs got no treatment for each of their illnesses, but was instead allowed to recuperate naturally.)

After ten weeks of conditioning, all the lambs were fed just one of the toxins at a time, then given a choice of the three cures. Only the lambs that had previously tried the medicines and recovered from each illness—as many as five months earlier—were able to select the appropriate medicine, demonstrating for the first time in nonhumans the ability to learn about a range of cures for different maladies. Villalba's study adds scientific weight to the idea that early humans may have acquired pharmacological knowledge by observing the foraging behavior of animals. (*Animal Behaviour,* in press, 2006) —*Nick W. Atkinson*

Mary's smart little lamb

Red Means Grow

Sunny but parched, or rainy but gloomy: only two seasons come and go in tropical rainforests, and which one might encourage more plant growth seems a toss-up. In the Amazon, it turns out, the dry season, roughly July through November, is the greener. Until recently, only a few locales had been studied, but in those areas the leaves fall early in the dry season, some of them choked by moss that prospers during the preceding rainy months. New growth replaces the dead leaves as the dry season advances. A new study shows that the same pattern applies to most of the Amazon basin, except where the forest has been disturbed by people.

Since 2000, a NASA satellite has recorded the amount of red light reflected by the Amazon rainforest. Plants absorb red wavelengths of light for photosynthesis, and reflect green. Thus, the less red they reflect, the more they are growing and greening up. A team led by Alfredo Huete, an ecologist at the University of Arizona in Tucson, found that, according to the satellite data, the greenery increased by 25 percent in the dry season. But where people had converted the forest to agriculture or other uses, the satellite detected exactly the opposite effect. In those areas, the red-light reflection indicated that the remaining flora had "browned down" by 25 percent.

Big rainforest trees have deep roots that can tap underground water reserves in all but the driest years, says Huete, so their growth depends more on sunlight than rain. The relatively puny vegetation in disturbed areas has no such advantage; it withers once the rains stop. (*Geophysical Research Letters* **33**:L06405, 2006) —*S.R.*

Genes Well Dropped

As a species evolves, its genome is constantly mutating, and some mutations can inactivate a gene. A disaster in the making? Not necessarily. Investigators have discovered that complete gene inactivation, or pseudogenization, can be beneficial—indeed, an important driving force for evolution.

Now three evolutionary geneticists have discovered that pseudogenes, or genes no longer expressed as functional proteins, may have contributed to humanity's divergence from chimpanzees. Xiaoxia Wang, Wendy E. Grus, and Jianzhi Zhang, all at the University of Michigan in Ann Arbor, identified sixty-seven pseudogenes in the human genome that originated in the time since the human and chimpanzee lineages split. One pseudogene, *CASP12,* which plays a role in suppressing mammals' immune systems, functions in all mammals except human beings.

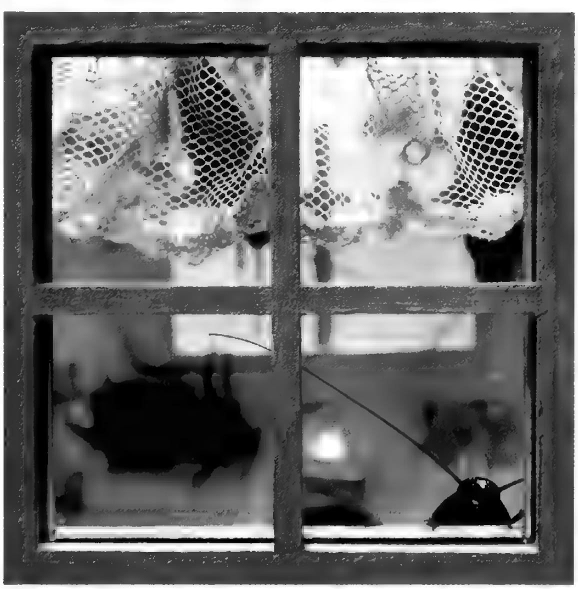
At some point in human evolution, shortly before modern *Homo sapiens* began to migrate out of Africa between 40,000 and 60,000 years ago, natural selection began to favor switching off the *CASP12* gene. This gene loss reduces the probability of developing severe sepsis, a disease in which the body responds too strongly to an infection. Although exactly how losing the protein that *CASP12* encodes can protect against severe sepsis is unknown, clearly, in some cases, less really is more. (*PloS Biology* **4**:0366–77, 2006) —*N.W.A.*

A Room with a Few

Cockroaches, to the dismay of many apartment dwellers, prefer group living. Safety in numbers is one benefit of a gregarious lifestyle, but togetherness can also have its drawbacks—not the least of which is increased competition for resources, including space. A recent study now shows that cockroaches respond to crowding by making complex collective decisions about how to achieve optimal group size and how to divvy up available nooks and crannies.

Jean-Marc Amé and José Halloy, both biologists at the Free University of Brussels, Belgium, and several colleagues presented groups of juvenile German cockroaches with shelters of varying number and size. When the roaches could choose among several roomy shelters, the entire group piled into a single one. But remarkably, when one of the shelters couldn't accommodate the whole crowd, the crafty insects distributed themselves into the smallest possible number of equal-size groups. For example, if three shelters were available that could house fifty roaches each, a group of eighty would invariably divide into two groups of forty—not, say, one of fifty and one of thirty, or three approximately equal groups. The insects' solution, according to mathematical models developed by the team, benefits all roaches equally and maximally.

So how do they do it? The group's uncanny behavior apparently results from decisions by individual cockroaches. Amé and Halloy posit that when an individual arrives at a shelter, the more roaches that are already there, the likelier it is to stay. If the space is too crowded, however, the benefits of refuge among its companions are reduced by the degree of competition for space, and the roach will scuttle off in search of another place to rest its antennae. (*PNAS* **103**:5835–40, 2006) —*N.W.A.*



Catherine Chalmers, Bathroom Window, *2004*

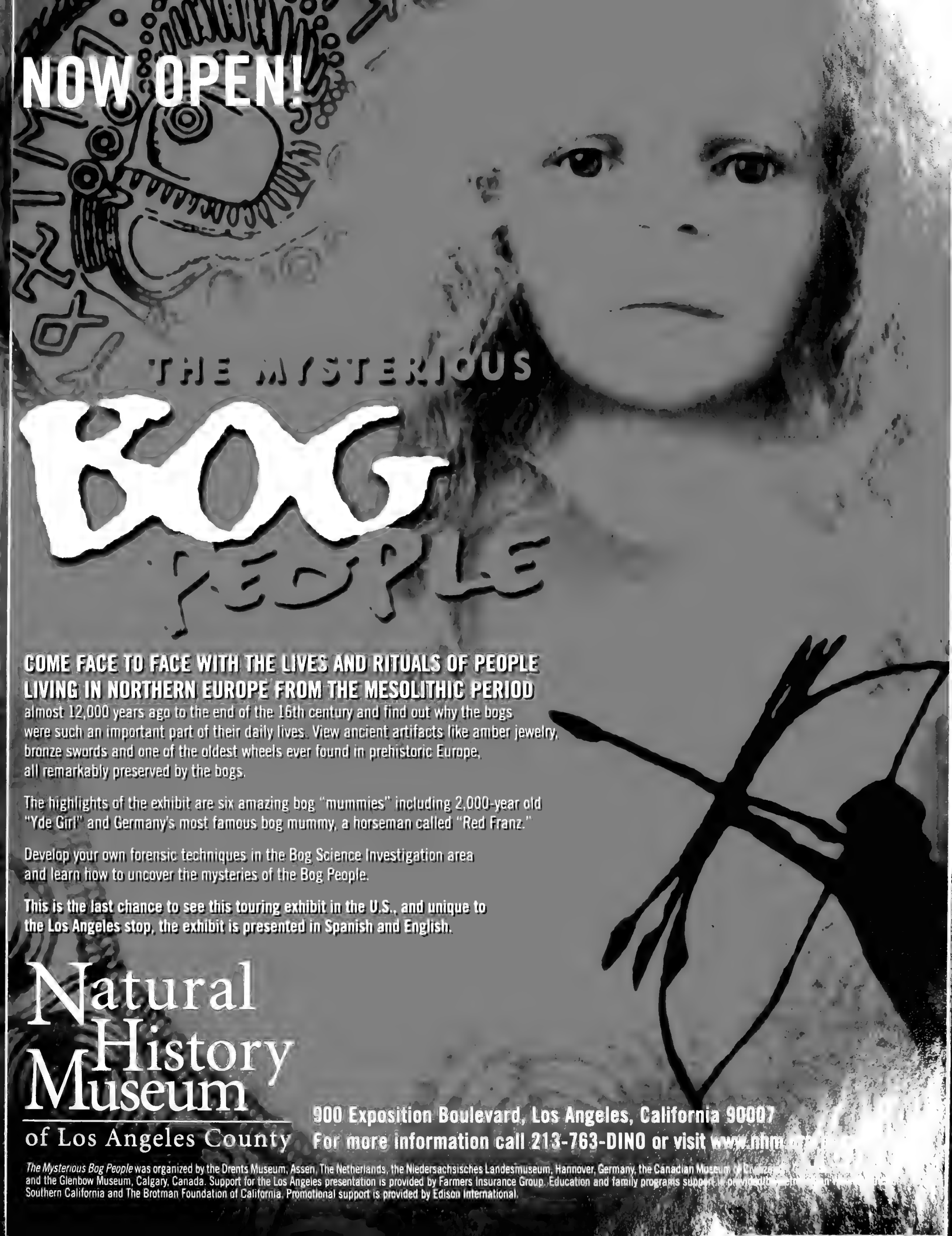
Spectral tarsiers: vicious in mobs

Harried by the Mob

When predators are afoot, prey have two options: fight or flight. Defending one's corner might sound honorable, but in a world "red in tooth and claw," honor usually ranks somewhere below self-preservation. So why, asked Sharon Gursky, a primatologist at Texas A&M University in College Station, should spectral tarsiers—tiny primates that weigh just four ounces—risk life and limb to face down a large and potentially lethal snake when they could run away instead?

The spectral tarsier is a nocturnal primate endemic to the Indonesian island of Sulawesi. Its tree-dwelling lifestyle makes it a target for hungry snakes. But rather than flee the scene when they spot a snake, the tarsiers often make loud calls that attract other tarsiers. The growing mob can swell to as many as ten, and the tarsiers may then spend as long as an hour harassing the would-be predator. Some of the pluckier primates may even dare to strike and bite the snake. The besieged predator typically retreats for cover, but often not before attacking its tormentors.

Gursky observed natural interactions and carried out experiments with tarsiers and rubber snakes. Most of the tarsier mob, Gursky discovered, belonged to a single social group, but adult males from other groups—often territorial rivals—frequently joined in, particularly when young females were nearby. One possible explanation for the seemingly foolhardy behavior, says Gursky, is that it enables males to demonstrate their prowess and hence their worth as future mates. Faint heart never won fair maiden. (*American Journal of Physical Anthropology,* **129**:601–8, 2006) —*N.W.A.*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Bushels of Bots

Africa's largest fly is getting a reprieve from extinction.

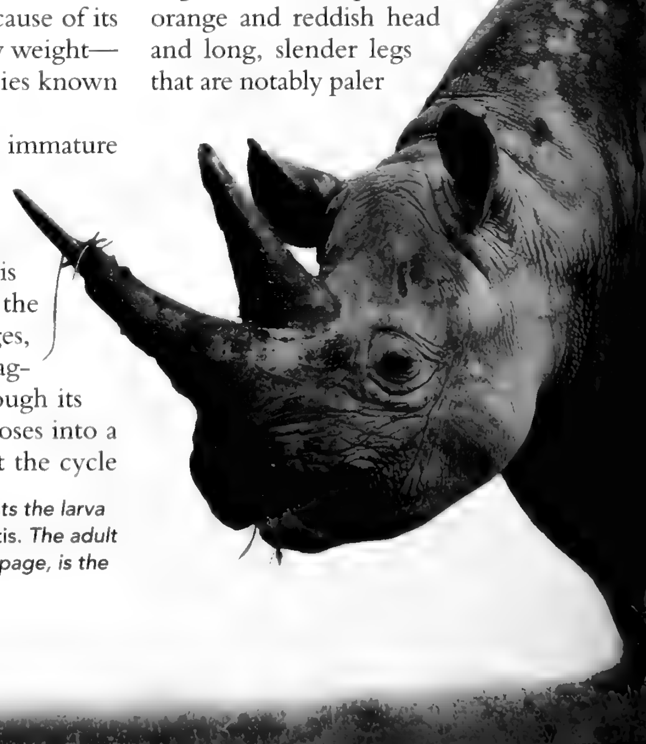
By David A. Barraclough

In the past 125 years all five of the world's rhinoceros species—the Indian, Javan, and Sumatran rhinos in Asia, and the black and white rhinos in Africa—nearly went extinct. And some of the African rhinos were quite literally taking a large fly with them on their slide toward extinction. Most people, even in scientific circles, had no idea the fly existed. They still don't. Certainly no one considered conservation programs for the fly while the rhinoceros populations were plummeting. Such a lack of concern about threats posed to insects and other invertebrates is not uncommon, but it is irresponsible. At least 95 percent of all animal species inhabiting the Earth are invertebrates, and so they constitute the bulk of animal diversity on the planet. Luckily for the endangered rhinoceros fly, conservationists were inadvertently drawn to its cause.

The plight of the big, charismatic rhinoceroses caught the world's attention in the 1990s; their populations had fallen drastically because of poaching, the illegal trade in their horns, and the destruction of their natural habitats. Today in Asia, only about 2,500 Indian, 300 Sumatran, and sixty Javan rhinos remain. Both African species, though, have benefited greatly from sustained and well-publicized conservation efforts. The white rhinoceros, the world's second-largest land mammal, has two subspecies, one of which lives in southern Africa and now numbers more than 11,000. After declining to as few as twenty individuals at the end of the nineteenth century, the southern white rhino has become one of Africa's biggest conservation success stories. (The other white rhino, a central African subspecies, numbered more than 2,000 in the 1960s, but only five or ten individuals are left, making it critically endangered.) Populations of the black rhinoceros fell by a staggering 96 percent between 1970 and 1992; the species is still endangered, but the population has risen to 3,500.

Rebounding from near extinction along with the black and white rhinos is a large fly, commonly known as the rhinoceros bot fly *(Gyrostigma rhinocerontis),* which parasitizes them. The fly has the distinction—because of its robust appearance and body weight—of being the largest fly species known in Africa.

Like other bot flies, the immature form of the insect is a spiny maggot, or bot, that burrows into its host and feeds off the host's tissues—in this case the gut of the black or the white rhino. After three stages, or instars, of growth, the maggot worms its way out through its host's anus and metamorphoses into a short-lived fly that can start the cycle over again by laying eggs on the hide of its host. Because *G. rhinocerontis* depends entirely on its hosts for survival, its numbers would have mirrored the rise and fall of rhinoceros populations in all parts of Africa. In some periods of the twentieth century, it must have been close to extinction.



Black rhinoceros (right) often hosts the larva of the fly Gyrostigma rhinocerontis. *The adult bot fly, shown actual size on this page, is the largest fly in Africa.*

About 24,000 known species of flies, in slightly more than a hundred different families, live in the Afrotropics, a region that includes sub-Saharan Africa, Madagascar, and associated islands in the Atlantic and Indian oceans. Beyond those species, a substantial number still await scientific description and classification. Estimates differ, but I would venture that at least 30,000 more African fly species remain unknown to science.

Even within that astonishing context, few entomologists would dispute the exceptional nature—both visually and biologically—of *G. rhinocerontis,* in the family Oestridae. The largest adult specimens grow as long as 1.6 inches, with wingspans as wide as 2.8 inches, making it one of Africa's most striking fly species.

The rhinoceros bot fly was originally discovered in the stomach of an African rhinoceros more than 160 years ago. The adult form of the species strongly resembles a large, blackish wasp, with an orange and reddish head and long, slender legs that are notably paler

than the rest of the body. The elongated wings are brown to black and, when the fly is at rest, run along almost the entire length of the body [*see photograph on opposite page*]. Adult flies occur in parts of Africa where their rhinoceros hosts live. In recent years that has meant the grasslands and savannas of southern and East Africa, but historically the flies and their hosts extended, except for the Congo Basin, across most of sub-Saharan Africa. No matter the flies' range, even the most experienced collectors have had a tough time finding them.

Two other bot-fly species of the genus *Gyrostigma* are known, and both are exceptionally rare. One of them, *G. conjungens,* was discovered in its bot form in the belly of a Kenyan black rhinoceros in 1901, but it hasn't been collected, or even seen again, since 1961. The other rare species, *G. sumatrensis,* is known only from a single bot, which was in the late developmental stage of the larva known as the third instar. It was discovered in a captive Sumatran rhinoceros and described in 1884, but it, too, has not been seen again. No *Gyrostigma* bot flies have been found in the Indian or the Javan rhinos, but it is not unreasonable to expect that the intestinal parasites may eventually be discovered in all five rhinoceros species.

In 1847 the French naturalist and explorer Adulphe Delegorgue described large numbers of bots in the stomach of a black rhinoceros from northeastern South Africa. He published this vivid description of them in his *Voyage dans l'Afrique australe* ("Travels in Southern Africa"):

> The *Rhinoceros Africanus bicornis* could well claim the title of foster father of bots. The imagination boggles at the quantity contained in his stomach; they could be shoveled out in bushels. . . . I am much inclined to think that the viciousness and ill-humor which characterize the *Rhinoceros Africanus bicornis* are due simply to the presence of thousands of these parasites and can be compared with the irritability of a man infested with tapeworm. However, in spite of their numbers, which sometimes seem to exceed all natural limits, bots do not, as far as I know, cause the death of indigenous animals.

Delegorgue was the first of many to become intrigued with the biology of *G. rhinocerontis.* Brian R. Stuckenberg, an African fly specialist who is also a former director of South Africa's Natal Museum, maintained an interest in *Gyrostigma* biology throughout his fifty-year career, continuing South Africa's tradition as the hub of research on African bot flies. Stuckenberg took the first of what are still only a few good photographs of living bots [*see photograph at top of this page*]. He and other entomologists working today, including myself, rely heavily on the pioneering studies of another famous fly taxonomist, Fritz K.E. Zumpt, who was based in South Africa and published his major works during the 1950s and 1960s.

What about the fly's behavior? Observing the flies in the field has been difficult. Many of the South African specimens studied by Zumpt and others were not wild; rather, they were reared from mature bots collected from the stomachs of dead hosts. Finding mature bots hasn't been easy, and getting mature flies to lay eggs has been even harder. Only a few large museum collections have the luxury of owning an adult specimen of *G. rhinocerontis,* and amateur collectors lucky enough

Stomach wall of a rhinoceros has become pitted from the depredations of bot-fly larvae, which parasitically feed on the rhino tissue. The three larvae in the photograph, shown actual size, are nearly ready to leave the rhino gut, pupate, and emerge as adult flies.

to have caught the elusive insect prize their specimen highly.

What makes the adult flies so hard to collect in the field? First, the airborne stage of their lives lasts only three to five days, severely limiting the collecting time. One reason the airborne stage is so short is that *Gyrostigma* flies have rudimentary, nonfunctional mouthparts; in fact, they probably don't feed at all during that stage. Even though they gorge themselves as larvae, stored energy goes quickly when you're flying but not eating. That could certainly account for their speedy demise.

A second reason the flies are hard to catch is that they probably do not fly extensively by day. The evidence is conflicting about when the adults are most active, and no one knows where they spend their time when they are neither flying nor laying eggs. Some observers have reported them flying near their rhinoceros hosts on hot, sunny days in northern KwaZulu-Natal, a province in eastern South Africa. But some entomologists think they are crepuscular, becoming active only at dawn or at dusk.

One explanation for the seeming contradiction may be that the two sexes keep to differing schedules. I believe that the female flies will prove to be most active during daylight hours, when they deposit their eggs on the hide of their hosts, and that the males are most active at dawn and dusk, when mating may take place. I have examined the specimens in the Natal Museum's collection—the largest fly collection in Africa—and all of our field-collected male flies were found at dusk.

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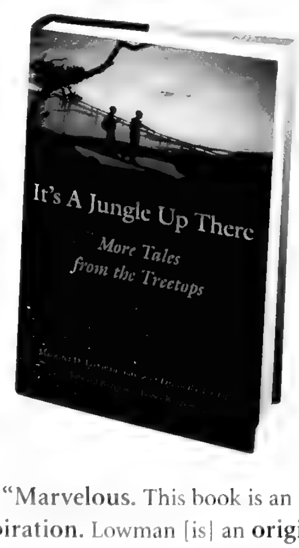

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giving credence to the crepuscular theory. But there is no solid information available about where mating takes place—if there were, the flies might be captured or at least observed.

Finally, the flies are fairly safe from the traps of insect collectors and entomologists because even the most daring collector never gets very close to the formidable rhinoceroses for long! In my twenty years of collecting flies in the field, I have managed to catch only one adult *Gyrostigma.* I was on a reserve in northern KwaZulu-Natal early one summer evening, and a male rhino fly loudly buzzed up to a light that I had set up in hopes of catching just such a specimen. I knew rhinos were in the area, but I was still surprised and delighted by my good fortune. Flies have been attracted to light traps in other parts of South Africa, as well; they were captured in Kruger National Park soon after rhinoceroses were re-introduced there from KwaZulu-Natal.

Pink bot-fly larvae in an intermediate, or second instar, stage of growth, feed on the stomach wall of a white rhinoceros that has just died (left). The larvae attach themselves with mouth hooks and spines, both visible in the photomicrograph (right), magnified 20X.

The life cycle of the rhinoceros bot fly begins when female flies deposit oblong-shaped eggs in crevices in the host's hide, apparently near the rhino's horns or elsewhere on the head. Precisely what happens next is unknown; I think it likely that once the eggs hatch, after about six days, the young bots enter the rhino through its mouth or nostrils and eventually attach themselves to the lining of the rhino's stomach wall. They hook into it with spines and a pair of well-developed mouth hooks: sicklelike structures at the anterior end of the bot [*see photomicrograph below*]. There the bots feed on their hosts' blood and tissue.

As the bot continues to eat away at the rhino, it progresses through two more stages of development. At the second instar, it is 0.8 inch long, and has developed more prominent spines. At the third and final instar, it reaches its full adult length, but the most striking feature of the third instar is the development of large bands of spines. Each band comprises three to four rows of sharp spines. The spines help the bots attach to the rhino's stomach and burrow into it, a process that leaves large pits in the stomach wall. No scar tissue seems to result from the pits, though, so they are thought to be benign.

Unlike their adult forms, the bots of *Gyrostigma* have often been found in large numbers inside a rhinoceros's stomach. Only once, though, have I had the good fortune of examining them. Parts of a freshly dead rhino, from Pilanesberg National Park, in northern South Africa, were couriered to me in a parcel (I could not get to the site in time for dissection). I found quantities of first- and second-instar bots still attached to the stomach wall of the dead rhino—not "bushels" of them, as Delegorgue described, but certainly fifty or more.

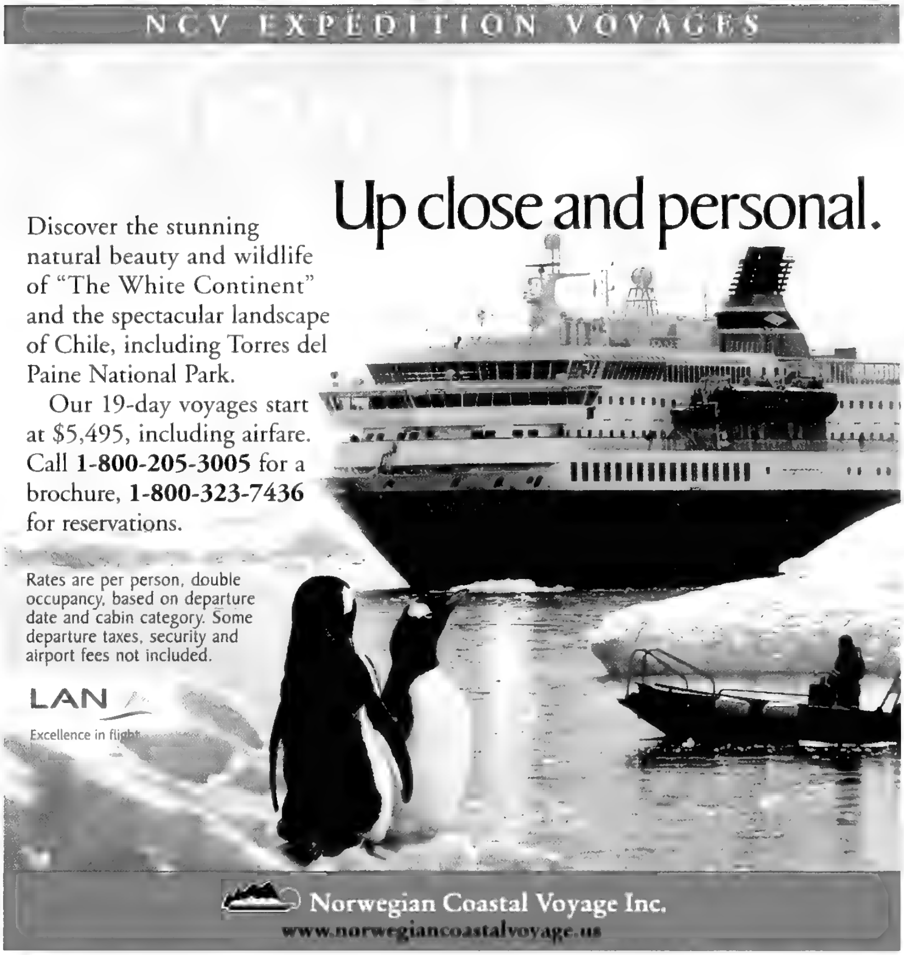
The bots were clustered in groups. The first instars were colored dark pink and buried deep within the mucosal folds of the stomach lining. The second instars were larger, a paler shade of pink, and more conspicuous because

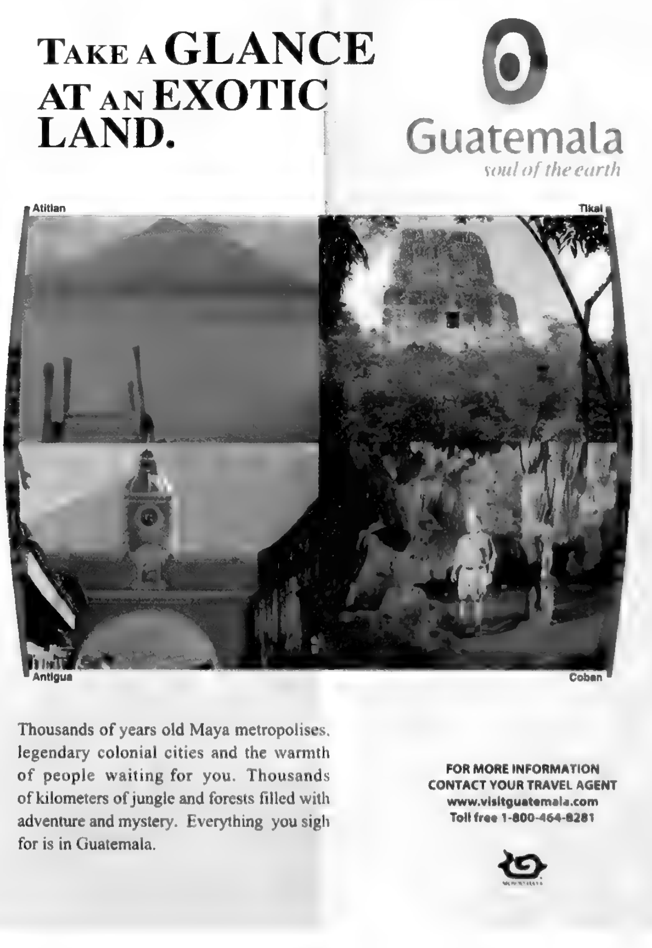
only their front ends were embedded in the mucosal folds. It is possible that the bots develop rather slowly, perhaps because they are competing with so many other sister bots, and overstressing their hosts would not be at all to their advantage. But that hypothesis awaits further confirmation.

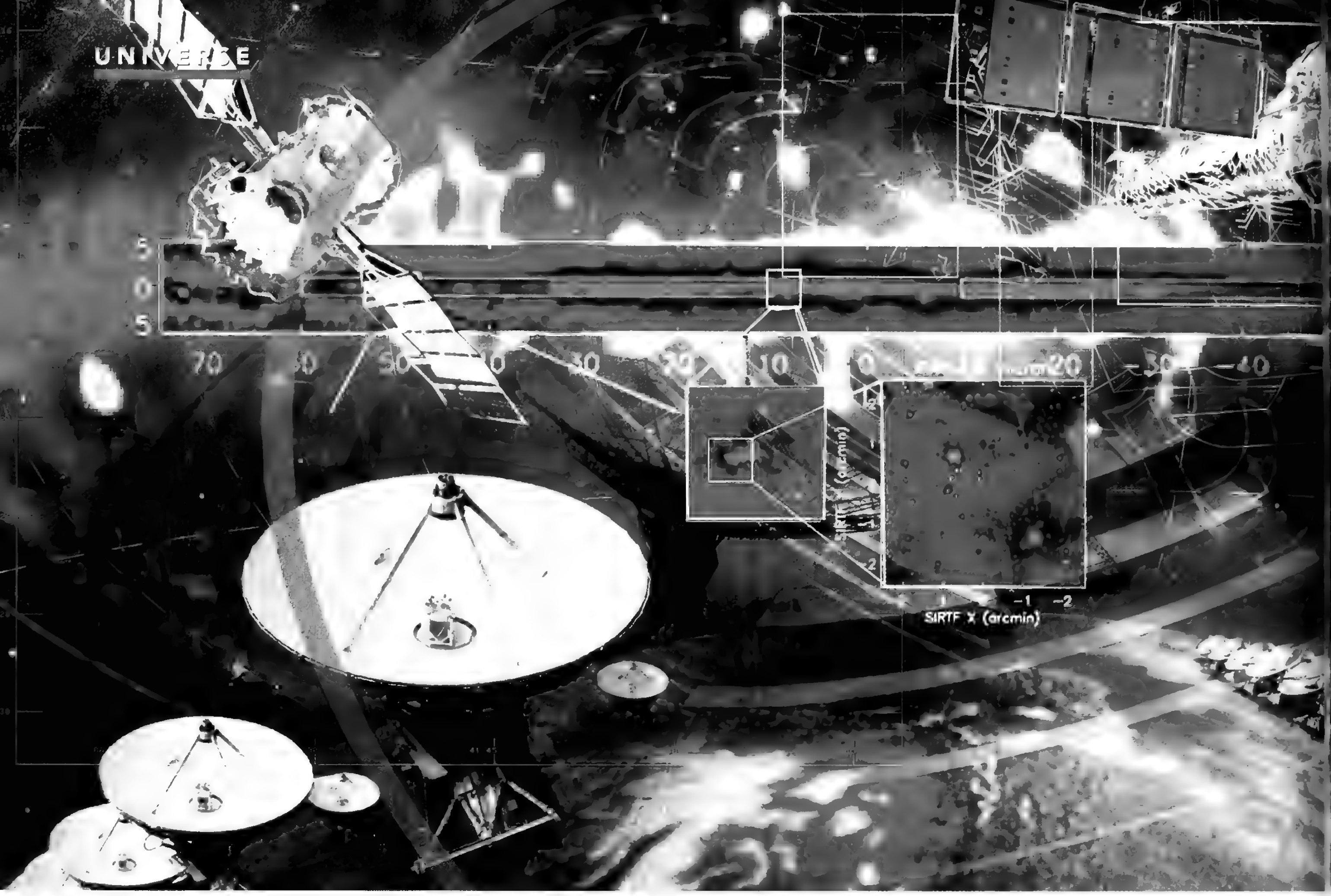
Unfortunately, "my" rhinoceros hosted no third-instar bots, so I wasn't able to rear adult flies. Mature third-instar bots are whitish to yellow with irregular dark brown spots—evidence of the internal changes they are making as they prepare to pupate. *G. rhinocerontis* then passes out through the host's anus. Zumpt's research showed that the black pupal cases do not occur in rhinoceros dung piles, which the males leave to advertise their presence and rank to other rhinos. So it is likely that the bots quickly burrow into the soil beneath the dung or pass out of the anus independently of defecation, burrowing somewhere away from the dung piles. After six weeks of pupating, the adult flies emerge.

Entomologists still have much to learn about these rare and amazing flies. By now, the basic biology of *G. rhinocerontis* has been extensively studied, but the nature of their interaction with Africa's rhinoceros species—the flies' exclusive hosts—still needs extensive probing. No one knows what effect the presence of hundreds of bots in the stomach has, if any, on the rhinoceros's temperament. Was Delegorgue right? Are rhinos more ornery because of their baggage of bots? Given the widespread, and continuing, concern about the conservation of both African rhinoceros species, that question, and related ones, will need to be answered. And answering them will prove useful in the understanding of at least two species, not just the more prominent one—whichever one that might be.

DAVID A. BARRACLOUGH is an investigator in Biological and Conservation Sciences at the University of KwaZulu-Natal in Durban, South Africa. He is currently taking part in a major taxonomic study of South Africa's tangle-veined flies, a group important in pollination biology.







"Unfit for Vision"

Much of the light gathered by today's telescopes is invisible.

By Neil deGrasse Tyson

Before 1800 the word "light," apart from its use as a verb and an adjective, referred just to visible light. But early that year the English astronomer William Herschel observed some warming that could only have been caused by a form of light invisible to the human eye.

Already an accomplished observer, Herschel had discovered the planet Uranus in 1781 and was now exploring the relation between sunlight, color, and heat. He began by placing a prism in the path of a sunbeam. Nothing new there. Sir Isaac Newton had done that back in the 1600s, when he also named the familiar seven colors of the visible spectrum: red, orange, yellow, green, blue, indigo, and violet. But Herschel was inquisitive enough to wonder what the temperature of each color might be. So he placed thermometers in various regions of the rainbow and showed, as he suspected, that different colors registered different temperatures.

Such a discovery would have satisfied most scientists, but Herschel then decided to put a thermometer in the dark, unlit area adjacent to the red end of the spectrum. Lo and behold, the temperature was even higher there than in the red. Herschel had discovered "infra" red light, the band just below red.

In the first of his four papers on the subject published in the Royal Society's *Philosophical Transactions* in 1800, Herschel details every variation he investigated. On page 17 he writes:

> [I] conclude, that the full red falls still short of the maximum of heat; which perhaps lies even a little beyond visible refraction. In this case, radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum as to be unfit for vision.

Herschel's eyepopper was the astronomical equivalent of Antoni van Leeuwenhoek's discoveries with a microscope, beginning in 1674, of "many very little living animalcules, very prettily a-moving" in the smallest drop of lake water. Other investigators immediately took up where Herschel left off.

In 1801 the German physicist and pharmacist Johann Wilhelm Ritter found yet another band of invisible light. But instead of a thermometer, Ritter placed a little pile of light-sensitive silver chloride in each visible color as well as in the dark, unlit area next to the violet end of the spectrum. Sure enough, the pile in the unlit patch darkened more than the pile in the violet patch. What's beyond violet? "Ultra" violet.

Sky watching didn't change overnight, though. The first telescope designed to detect invisible parts of the electromagnetic spectrum wouldn't be built for 130 years. That's well after radio waves, X rays, and gamma rays had been discovered, and well after the German physicist Heinrich Hertz had shown that the only real difference among the various kinds of light is the frequency of the waves in each band. In fact, credit Hertz for recognizing that there *is* an electromagnetic spectrum. In his honor, the unit of frequency for anything that vibrates, including sound, has duly been named the hertz.

Today, telescopes operate in every invisible part of the spectrum—from low-frequency radio waves a dozen meters long to high-frequency gamma rays no longer than a quadrillionth of a centimeter. That rich palette of light supplies no end of astrophysical discoveries. Want to peek at a stellar nursery deep inside a gas cloud? Check it out through NASA's infrared Spitzer Space Telescope. Want to measure the spectrum of supermassive black holes colliding in the center of a galaxy? Take aim with the Chandra X-Ray Observatory. Want to watch the explosion of a giant star, whose mass is as great as forty suns? Catch the drama via the European Space Agency's International Gamma-Ray Astrophysics Laboratory.

A telescope is merely a tool to augment our meager senses, enabling us to get better acquainted with faraway places. The bigger the telescope, the dimmer the objects it brings into view; the more perfectly shaped its mirrors, the sharper the image it makes; the more sensitive its detectors, the more efficient its observations. But in all cases, every bit of information a telescope delivers to the astrophysicist comes to Earth on a beam of light.

Somehow, though, astronomers were a bit slow to make the connection between the newfound invisible bands of light and the idea of building a telescope that might detect those bands from cosmic sources. Surely hubris takes some of the blame: how could the universe possibly send us light that our marvelous eyes cannot see? For more than three centuries—from Galileo's day until Edwin Hubble's—building a telescope meant only one thing: making an instrument to catch visible light [*see "The Light Brigade," by Neil deGrasse Tyson, March 2006*]. Celestial happenings, however, don't limit themselves to what's convenient for the human retina. Instead, they emit varying amounts of light simultaneously in multiple bands. So, without telescopes and detectors tuned across the spectrum, astrophysicists would still be blissfully ignorant.

Take an exploding star—a supernova. It's a cosmically common and seriously high-energy event that generates prodigious quantities of X rays. Sometimes bursts of gamma rays and flashes of ultraviolet accompany the explosions, and there's never a shortage of visible light. And long after the explosive gases cool, the shock waves dissipate, and the visible light fades, the supernova "remnant" keeps on shining in the infrared. Most stellar explosions take place in distant galaxies, but if a star blows up within our own Milky Way, its death throes are bright enough for everyone to see, even without a telescope. No one on Earth saw the X rays or gamma rays from the last two supernova spectaculars hosted by our galaxy, in 1572 and 1604, but their wondrous visible light was widely reported.

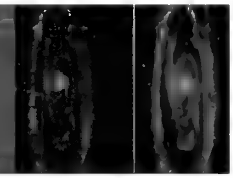
Problem is, no single combination of telescope and detector can see every feature of such explosions, because no such combination can see every band of light. In fact, the range of wavelengths that make up each band strongly influences the design of the hardware used to detect it. For the moment, think of light as made up of waves. Each beam of light has a measurable wavelength: the distance between consecutive crests (or troughs) of a single wave. Only after you identify the wavelength range of your astronomical affections can you begin to think about the size of your mirror, the materials you'll need to make it, the shape and surface it must have, and the kind of detector you'll need.

X-ray wavelengths, for example, are extremely short. So if you're gathering X rays, your mirror had better be supersmooth, lest it distort them. But if you're gathering long radio waves, your mirror could be made of chicken wire that you've bent with your hands, because the irregularities in the wire would be much smaller than the wavelengths you're after. Of course, you also want plenty of detail—high resolution—and so your mirror should be as big as you can afford to make it. In the end, your telescope must be much, much wider than the wavelength of light you aim to

detect. And nowhere is this need more evident than in the construction of a radio telescope.

Radio telescopes, the earliest non-visible-light telescopes ever built, are an amazing species of observatory. The American engineer Karl G. Jansky built the first successful one between 1929 and 1930. It looked a bit like the moving sprinkler system on a farmerless farm. Made from a series of tall, rectangular metal frames secured with wooden cross-supports and flooring, it turned in place like a merry-go-round.

The first radio telescope looked like the mobile sprinkler system on a farmerless farm.



Jansky had tuned the hundred-foot-long contraption to a wavelength of about fifteen meters, corresponding to a frequency of 20.5 megahertz. Jansky's agenda, on behalf of his employer, Bell Telephone Laboratories, was to study any hisses from Earth-based radio sources that might contaminate terrestrial radio communications.

The result of Jansky's labors, "Electrical Disturbances Apparently of Extraterrestrial Origin," appeared in *Proceedings of the Institute for Radio Engineers* in 1933. By spending a couple of years painstakingly tracking and timing the static hiss that registered on his jerry-rigged antenna, Jansky had discovered that radio waves emanated not just from regional thunderstorms but also from the center of the Milky Way. That region of the sky swung by the telescope's field of view every twenty-three hours and fifty-six minutes: exactly the period of Earth's rotation in space and thus exactly the time needed to return the galactic center to the same angle and elevation on the sky.

With that observation, radio astronomy was born—minus the radio astronomers. Jansky was retasked within Bell Labs and did not pursue the fruits of his own seminal discovery. Four years later, though, a self-starting American named Grote Reber, from Wheaton, Illinois, built a thirty-foot-wide, metal-dish radio telescope in his own backyard. In 1938, under nobody's employ, Reber confirmed Jansky's discovery, and then spent the next five years making low-resolution maps of the radio sky.

Reber's telescope, though without precedent, was small and crude by today's standards. Modern radio telescopes are quite another matter. Unbound by backyards, they're sometimes downright humongous. MK 1, which began its working life in 1957, is the planet's first genuinely gigantic radio telescope—a single, steerable, 250-foot-wide, solid-steel dish at the Jodrell Bank Observatory near Manchester, England. A couple of months after MK 1 opened for business, the Soviet Union launched *Sputnik 1,* and Jodrell Bank's dish suddenly became just the thing to track the little hunk of orbiting hardware—making it the forerunner of today's Deep Space Network for tracking planetary space probes.

Another variety of radio telescope, the interferometer, comprises arrays of identical dish antennas, spread across swaths of countryside and electronically linked to work in concert. The resulting signal is a single, coherent, high-resolution image of radio-emitting cosmic objects. Although "supersize me" was the unwritten motto for telescopes long before the fast-food industry co-opted the slogan, recent radio interferometers form a jumbo class unto themselves. They include the Very Large Array, with twenty-seven eighty-two-foot dishes positioned on tracks crossing twenty-two miles of desert plains near Socorro, New Mexico; the Very Long Baseline Array, with ten eighty-two-foot dishes spanning 5,000 miles from Hawai'i to the Virgin Islands; and the Giant Metrewave Radio Telescope, thirty 148-foot lightweight mesh dishes spanning sixteen miles of arid plains east of Mumbai, India. In the past decade, those engineering marvels have unveiled stunning phenomena in our own galaxy. One, announced this past February, is a young star 500 light-years from Earth that's ringed by an inner disk of dust orbiting one way and an outer disk orbiting the opposite way. Another is a pulsar speeding out of our galaxy fast enough to travel from New York to London in five seconds.

And just wait until the sixty-four antennas of ALMA, the Atacama Large Millimeter Array, start observing from the remote Andes of northern Chile. Tuned for microwaves, whose wavelengths (the second longest, after radio waves) range from fractions of a millimeter to several centimeters, ALMA will give astrophysicists high-resolution access to categories of cosmic action unseen in other bands. ALMA's location is, by intention, the most arid landscape on Earth—three miles above sea level and well above the wettest clouds. Water may be fine for microwave chefs but it's bad for astrophysicists, because the water vapor in Earth's atmosphere chews up pristine microwave signals from across the galaxy and beyond.

All those (and other, yet-to-be-built) arrays will give astrophysicists a strikingly better look at known objects and phenomena. In addition, the arrays will help answer some big outstanding questions, such as what dark matter is made of, what dark energy might be, and how galaxy clusters have evolved since birth. Testing the fundamental tenets of Einstein's general relativity is also in the cards.

At the ultrashort-wavelength end of the electromagnetic spectrum are high-frequency, high-energy gamma rays, whose wavelengths are measured in picometers. Discovered in 1900, they were presumed as early as the 1940s to be of cosmic origin. But no one actually detected them from space until a new kind of telescope was placed aboard NASA's *Explorer XI* satellite in 1961.

Anybody who's watched too many

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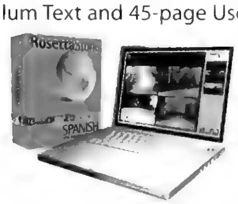

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sci-fi movies knows that gamma rays are bad for you. They're also hard to trap, because they pass right through lenses and mirrors. How, then, to observe them? The guts of *Explorer XI*'s telescope held a device called a scintillator, which responds to an incoming gamma ray by pumping out electrically charged particles. By measuring the energies of the particles, you can tell what kind of radiation created them. During the four months that *Explorer XI* tumbled through space, its telescope gathered data for twenty-three days and snared twenty-two certified gamma-ray hits.

Two years later the Soviet Union, the United Kingdom, and the United States signed the Limited Test Ban Treaty, which prohibited nuclear testing in the atmosphere, in space, and underwater. The Cold War was on, and so, to monitor the Soviets, the U.S. deployed a new series of satellites, the *Velas*, to scan for the invisible light that would result from aboveground nuclear tests. What the satellites found instead were almost daily bursts of gamma rays, later shown to be the calling card of distant stellar explosions.

During the 1990s NASA began its Great Observatories program: four state-of-the-science spaceborne telescopes, each covering a chunk of the electromagnetic spectrum that does not fully penetrate, or is otherwise altered by, Earth's atmosphere. The first was the Hubble Space Telescope, which detects primarily visible and ultraviolet light. The second, which operated until June 2000, was the Compton Gamma Ray Observatory. The third and fourth—the Chandra X-Ray Observatory and the Spitzer Space Telescope, for infrared—are, like the Hubble, still operating. As for radio telescopes, the big ones don't fit into contemporary spacecraft. Fortunately, Earth's atmosphere is transparent to most radio waves, so radio telescopes needn't be spaceborne to do good work.

While still taking data, the Compton Observatory saw something as unexpected as the *Velas*' discoveries: gamma rays right near Earth's surface. Turns out, as is evident from the fact that you're reading this sentence, that not all bursts of gamma rays are equally lethal [*see "Knock 'Em Dead," by Neil deGrasse Tyson, May 2005*], nor are they all of cosmic origin. In fact, a team of gamma-ray sleuths recently concluded that at least fifty bursts emanate daily near the tops of thunderclouds, a split second before ordinary lightning bolts strike.

Despite all the mind-blowing discoveries made at nonvisible wavelengths, visible-light instruments still have the power to shock and awe. In September 2005, astrophysicists using the Visible Multi-Object Spectrograph of the European Southern Observatory's Very Large Telescope array announced they had found a group of galaxies some 13.5 billion light-years from the Milky Way. A more distant object has never been seen. Nothing has ever been observed from so long ago, mere moments after the beginning of what we all know as time.

Yearning to see the universe for what it is—a stupendously rich collection of objects and phenomena waiting to be understood—today's astrophysicists have armed themselves with telescopes strategically positioned across the electromagnetic spectrum. Newton wasn't thus equipped. In thirty-one unanswered Queries appended to later editions of his *Opticks: Or, A Treatise of the Reflections, Refractions, Inflections and Colours of Light,* first published in 1704, he deeply pondered the unexplained nature of nature. At the end of Query 25 he asks "whether the Rays have not more original Properties than are yet discover'd." Comprehensive though it was, *Opticks* explored only the visible spectrum. Little could Newton have known how many more Properties were as yet undreamt of in his philosophy.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. An anthology of his* Natural History *essays,* Death by Black Hole: And Other Cosmic Quandaries, *will be published this year by W.W. Norton.*

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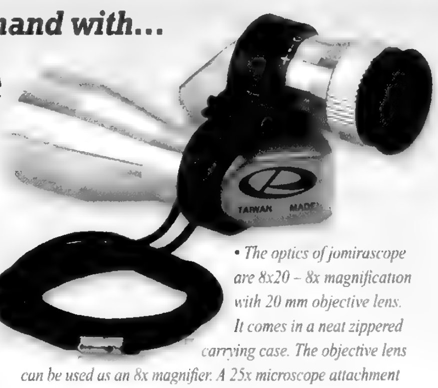

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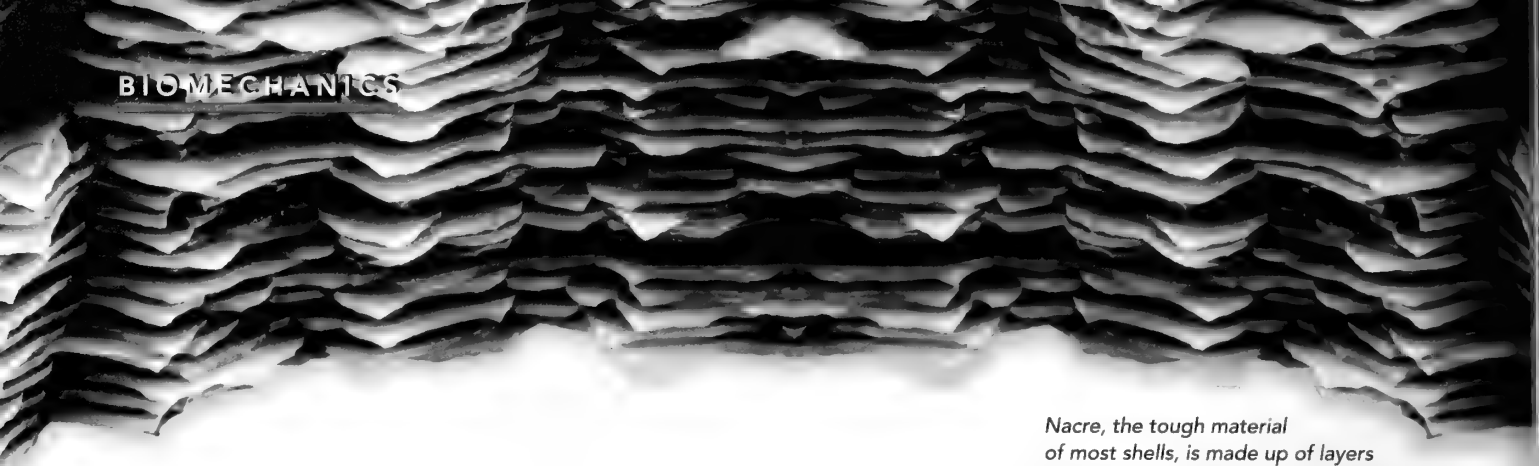


Nacre, the tough material of most shells, is made up of layers of calcium carbonate interleaved with layers of organic glue. This cross section of nacre is magnified 2,750×.

Tough As Shells

A promising candidate for artificial bone

By Adam Summers ~ Illustrations by Tom Moore

Biomimetics, the art and science of transferring biological designs into the realm of human use, is far from a straightforward process. The path from theory to product tends to be so convoluted that only a handful of biomimetic products are commercially viable—Velcro sticks out as a rare success. One of the holy grails of biomimetics is artificial bone, which promises to be both useful and marketable. After all, baby boomers are rapidly losing, breaking, and wearing down their natural supply; the demand for replacement bone within their generation alone is high enough that biomimeticists would turn nature inside out to find a solution.

It so happens that nacre, the brick and mortar of most mollusk shells, can take quite a beating—which is why such otherwise defenseless, soft-bodied creatures go to the trouble of making the stuff. Nacre is mainly made of a ceramic, a hard nonmetallic mineral—calcium carbonate in this case. What's intriguing is that unlike your favorite coffee mug or run-of-the-mill grail, nacre is a ceramic that is unusually tough. Typically the smallest crack in a ceramic object races through the brittle structure to cause a full-blown failure. You may have noticed how seldom you find a mug or a plate that's nearly, but not completely, broken.

But nacre is not a simple or homogeneous piece of clay. Rather, like my favorite pastry, the napoleon, nacre is made of thin sheets of ceramic interleaved with even thinner sheets of organic glue. Although one ceramic sheet is easy to fracture, the crack stops when it hits the gluey interface, and more energy must be spent to start the crack in the next layer [*see micrograph at top of page*]. Incidentally, those thin sheets are about the same thickness as wavelengths of visible light, which explains why the insides of abalone shells—made of nacre—reflect a rainbow of colors.

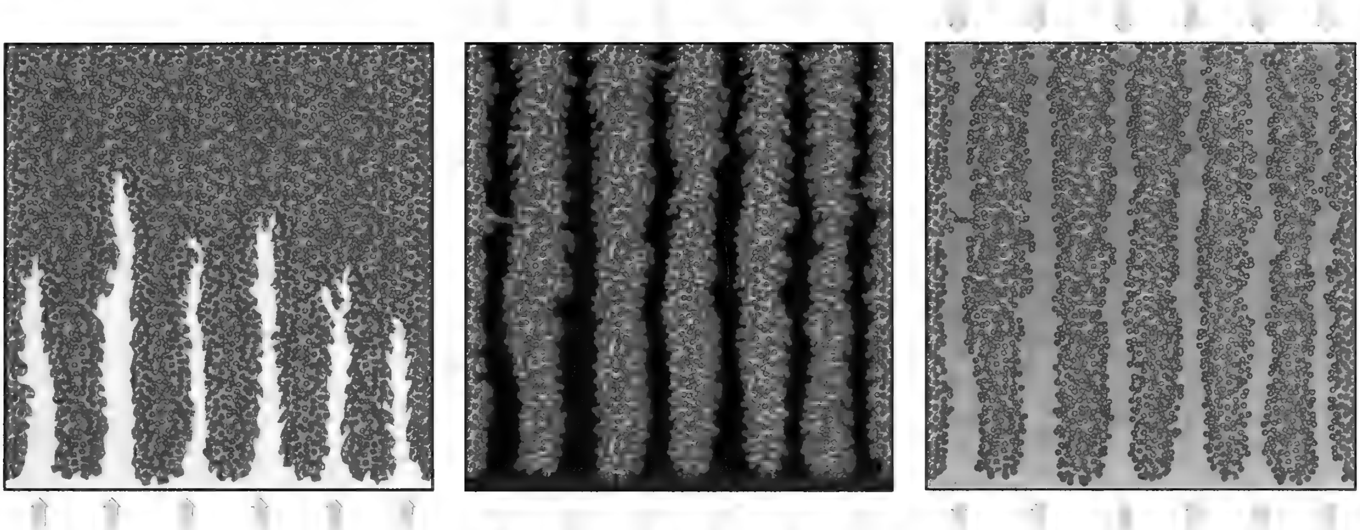
As it happens, your skeleton, too, is made up largely of a ceramic: hydroxyapatite. When it's healthy, it doesn't shatter nearly as easily as a cup or a bowl either. That is because an organized network of collagen fibers toughens the bone, and a lattice of little struts forms a spongy, energy-dissipating framework for most of your bones. If nacre could be sculpted into the shape of patellas or pelvises, the material might be just what the doctor ordered. Nacre is more similar to bone, and would likely make a better match, than titanium or stainless steel, when a new joint is needed for an aging hip or a demolished elbow.

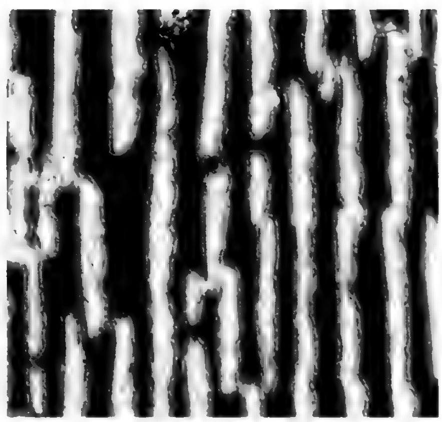
Unfortunately, although the structure and remarkable properties of nacre have been known for thirty years, the simplicity of the material is deceptive. So far no one has been able to make synthetic nacre. Most attempts have focused on alternating a layer of ceramic with a wash of glue, and repeating that *ad nauseum*. The process ends up with a nacrelike material, but the thickness of the ceramic layers is hard to control, and it takes thousands of cycles to produce a slab of appreciable heft. More important, the interface between glue and ceramic—so critical in stopping cracks from propagating through a natural shell—has proved extremely hard to copy from nature. Ceramic bone implants currently on the market apparently wear well, but they are more brittle than healthy bone.

Another approach now seems much more promising. Antoni P. Tomsia, a materials scientist at the Lawrence Berkeley National Laboratory in California, and his team have taken advantage of the properties of freezing water to make a finely layered composite that's amazingly tough. Two such properties, seemingly irrelevant to making bone, led to the new tech-

nique for fabricating nacre. First, seawater doesn't freeze uniformly: pure water crystals segregate themselves from salt and other suspended impurities. Second, the growth of this pure ice can be controlled to produce broad, flat crystals; the crystals naturally organize themselves in such a way that distinct layers of pure water-ice crystals and layers of salt or other particles are formed. The result looks a lot like nacre but on a much larger scale. Tomsia's team discovered that by increasing the rate at which water freezes, they could make the layering progressively finer.

To make synthetic bone, the team adds granules of hydroxyapatite to the water, then freezes the mixture at a very low temperature. The result is a finely layered composite of ice and mineral. Now they can remove the water by freeze-drying the composite, which leaves a complex, layered structure of hydroxyapatite. The structure has rough surfaces, as does natural nacre. Some hydroxyapatite granules that span the spaces left behind by the sublimated ice add support, and a quick blast of heat—not unlike the firing of clay in a kiln—further strengthens the lattice. Finally, an epoxy is added to the dried block of hydroxyapatite in a vacuum; the epoxy infiltrates the spaces between the plates where the ice used to be and mimics the organic glue layer of nacre [*see diagrams below*].





Artificial nacre can be made by freezing a slurry of water and ceramic particles, which forces the particles into distinct layers between growing, self-organizing ice crystals (see schematic diagram, above left). The pure ice crystals are freeze-dried, leaving vertical voids between pillars of ceramic (above middle). Glue is then forced into the voids and allowed to harden (above right). The final product, shown in the photomicrograph at right, approaches natural nacre in strength and toughness, but the layers of the natural substance are substantially thinner. The photomicrograph is magnified 260×.

One advantage of Tomsia's system is that the final product closely matches the shape of the freezing container. That makes it possible to mold the blocks according to the bone that must be replaced. Furthermore, since varying the freezing rate can change the thickness of the layers, composites can be formed that have, say, a core that is more dense than its shell. Unfortunately, a practical method of making this material in bulk and molding it to exact specifications has yet to be tested. Tomsia's group is also working to achieve even thinner layers in their faux nacre.

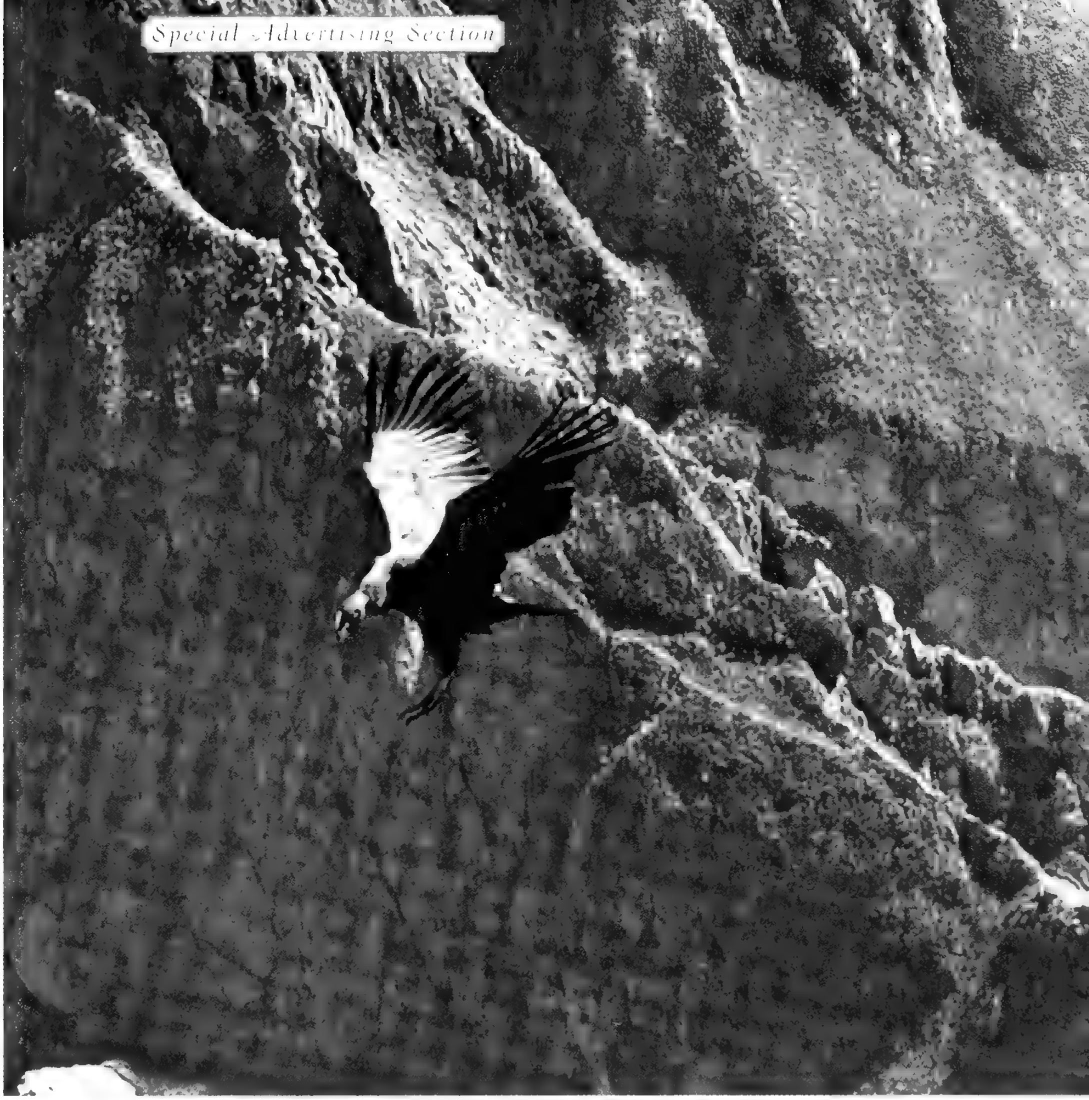
Nature offers an infinite variety of biological designs, free for the taking. But exploiting nature's solutions to structural problems requires a team with disparate talents and a large dose of patience. Bone continues to pose a challenge to bioengineers and biomechanists. As Tomsia's method and other competing products take the stage, I wish them all the time-honored words of good luck: "Break a leg." And if someday the phrase turns from theatrical encouragement into literal description, I might find myself very grateful to be patched up with the architectural stuff of seashells.

ADAM SUMMERS (asummers@uci.edu) *is an assistant professor of bioengineering and of ecology and evolutionary biology at the University of California, Irvine.*

PERU

PERU IS HOME TO ANCIENT CULTURES and a rich colonial tradition, and nature lovers know it is one of Earth's most biodiverse places. It has nearly 20 percent of the world's birds and 10 percent of the world's reptiles, and it has set aside 13 percent of its territory into protected natural areas.

Start your trip in the colonial cities of Lima or Cusco, which have numerous historical sites, all the sophistication and luxuries of modern urban centers, and can serve as the base for further adventures. You might explore the Nazca lines, take a boat ride on Lake Titicaca, or hike along ancient Incan paths in the Andes. From Cusco, you will want to see the spectacular ruins of Machu Picchu, about forty miles northwest of the city. Constructed between AD 1460 and 1470, and including about 200 buildings, Machu Picchu must have served as an Incan royal estate or religious retreat. Cusco is also a good starting point for a trip across the Andes to the Amazon, where you can spend a few days exploring Manu National Park. The park comprises the watershed of the Manu River, which flows along an extraordinary range of altitudes, from the high Andean plain down to the Amazon Basin. Manu is home to 20,000 plant varieties, 1,200 butterfly species, 1,000 bird species, 200 species of mammals, and countless reptiles, amphibians, and insects.

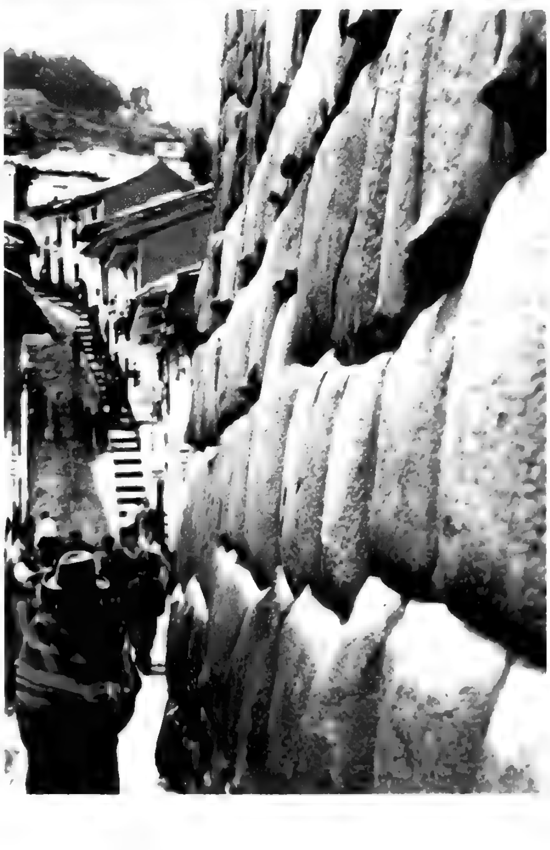


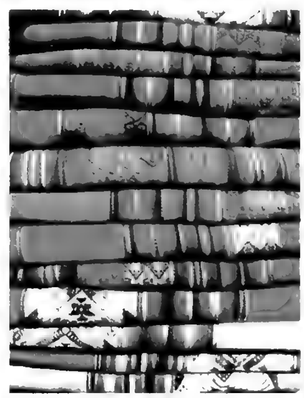
In the Manu rain forest, look for rare species such as the giant otter and the giant armadillo, and jaguars, which are often sighted here.

A more out of the way but spectacularly beautiful national park is Mount Huascaran. Set in the Andes Mountains' Cordillera Blanca, the world's highest tropical mountain range, the park includes the mountain of the same name, which towers at over 22,000 feet, as well as 26 other snow-capped peaks over 19,000 feet tall. Its 120 glacial lakes, glaciers, rivers, deep ravines, thermal springs, and varied vegetation—from humid montane forest to alpine tundra to puna plateaus—are home to the spectacled bear, the puma, vicuna, and North Andean huemul, a rare type of deer; notable birds include the Andean condor, giant hummingbird, and cordillera hawk. Allow yourself a few days here to acclimate to the high altitude.

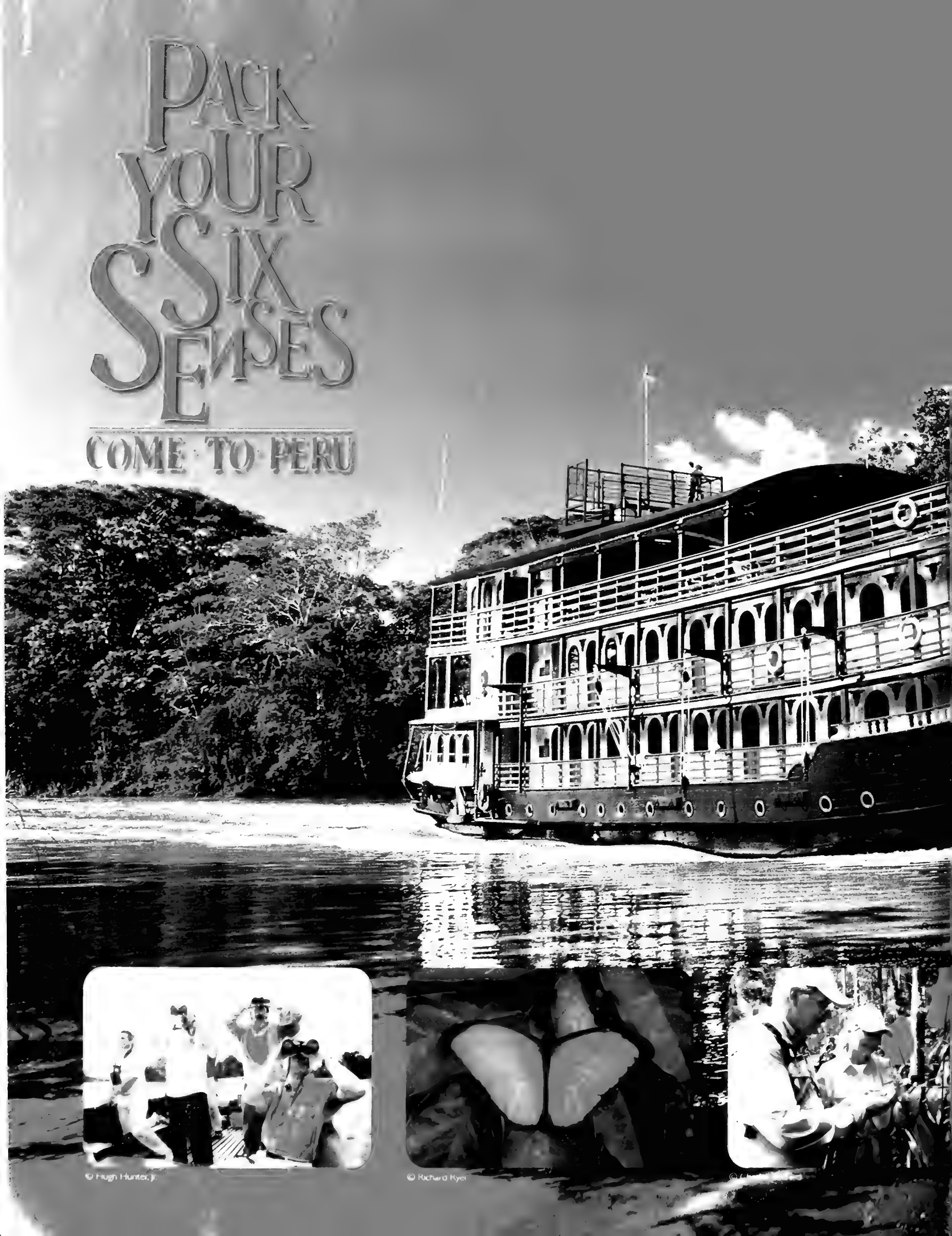
Also off the beaten track but worthwhile is the Cerros de Amotape National Park in northwestern Peru. The park protects the vast equatorial dry forests of the Amotape Cordillera and its surrounding valleys, once intensely harvested for their valuable hardwoods, and tropical Pacific forests. The park shelters two endangered species on the brink of extinction: the American crocodile and the northeastern otter. It's also home to Tumbes howler monkeys, ocelots, and more than 100 bird species, many of which are endemic, such as the white-winged guan and the northern magpie.

No matter how far-flung your destinations, Peru is easy to visit and travel in, thanks to its highly developed transportation network and hotel infrastructure. It has 36 airports, and 9 of these are international. For more information, visit www.peru.info.





Left Machu Picchu. Top Condor about to land on the Andes. Incan wall in Cusco, stack of colorful traditional Peruvian fabrics at a market in Pisac



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Origins of Floral Diversity

A quarter-million flowering plants attest to a highly flexible developmental recipe. Plant biologists have now proposed a genetic model that may account for the profusion of floral forms.

By Amy Litt

Colorful petals, sweet perfumes, and delicate shapes make flowers a delight to the senses. Each of the 250,000 species of flowering plants—the plant division known as angiosperms—makes a distinct flower, and the resultant diversity boggles the mind. Showy, exuberant flowers—roses, lilies, orchids—catch people's attention, but many plants flower without making such a fuss of it: think of the oaks, maples, and grasses. Flowers may grow singly, as tulips do, or with companions on a common stem, called an inflorescence, as the banksia does [*see rightmost photograph on opposite page*]. They may be radially or bilaterally symmetrical, tubular in form or dish-shaped. Flowers may lack one or another kind of organ altogether (poinsettias, for instance, lack petals—their showy display is formed out of modified leaves that eclipse small, petalless flowers), or yield a profusion of them. Each kind of organ, moreover, may be fused or separate, standard issue or tricked out to entice a specific pollinator. Petals may be fringed, spiky, or spurred; stamens may be stiff, droopy, or jiggly; the variations go on and on. Most people are content to take pleasure in the sheer abundance and variety of flowers, but we evolutionary botanists are less easily gratified. What is the origin of such extraordinary diversity of flower form, we wonder? What is the genetic basis of all this evolutionary innovation?

Flowers exhibit lavish variety in shape and color, as well as in the number and arrangement of their organs. The flowers pictured here, not all shown to the same scale, suggest some of that diversity. They are (left to right): passionflower, tulip, Queen Anne's lace (in background, throughout), poppy, tulip, thistle, chrysanthemum, and banksia. What may appear to be a single flower in Queen Anne's lace, chrysanthemum, or banksia is actually made up of many individual flowers; together, they constitute an inflorescence.

All flowers—large or small, gaudy or spare—follow the same basic steps as they form. Each starts off as a floral meristem, a mound of rudimentary, unspecialized cells—the plant equivalents of embryonic stem cells. Meristems are made up of four concentric circular regions, or whorls; each whorl develops into one kind of flower organ. The outer whorl becomes the sepals. The next whorl in becomes the petals. The two innermost whorls become the reproductive organs: the male stamens, which make pollen, then the female carpels, which enclose egg-containing ovules, at the flower's center.

Since the multitude of flower forms are all built according to that plan, it seems reasonable to suppose that a standard set of genetic instructions directs the basic program of flower-organ development, with variations on those instructions specific to the roses, the lilies, and the rest of the great bouquet. Thus two questions propel the work of the evolutionary botanist: What are those basic instructions, and what are the variations?

The most widely accepted account of the basic instructions for flower-organ development is known as the *ABC* model. The name comes from the three roles (called *A*, *B*, and *C*) that genes are thought to play in directing how the mass of floral-meristem cells grows and specializes into sepals, petals, stamens, and carpels. The genes in question are transcription factors, a powerful kind of gene that all organisms possess, from bacteria on up the evolutionary ladder. The power of a transcription factor is that it can control other genes by turning them on or off. Thus the activation of one transcription factor in a cell can initiate entire cascades of molecular activity in that cell.

One important role of transcription factors is to determine the fate of an immature cell. They do so by setting in motion chemical activity that changes the immature cell into a muscle cell or a liver cell, a petal cell or a pollen cell. Furthermore, many of the genes that control flower formation are a particular kind of transcription factor known as a *MADS*-box gene. *MADS*-box genes control the identity and structure of many plant organs, just as *Hox* genes control body-plan development in animals [*see "The Origins of Form," by Sean B. Carroll, November 2005*].

Since transcription factors are so powerful, evolutionary changes in them can lead to dramatic changes in a species. And sure enough, the main transcription factors that play a role in flower formation have undergone a great deal of evolutionary change and proliferation, which accounts for much of the floral diversity among the angiosperms.

One kind of evolutionary change, the duplication of genes, appears to have been particularly important. My work with Vivian F. Irish, a plant biologist at Yale University, has revealed numerous instances of gene duplication in the evolutionary history of one flower-forming gene lineage. It even hints at the origin of the first flower. Finally, it suggests that *Arabidopsis thaliana,* the plain little member of the mustard family that provided most of the evidence for the *ABC* model, may turn out to be unusual in the way it makes its flowers. That discovery, together with others, shows that the *ABC* model—and thus the evolutionary botanist's understanding of the basic instructions for flower-organ development—must now be modified.

The *ABC* model of flower-organ development was articulated in 1991 by two plant biologists, Enrico Coen of the John Innes

Centre in Norwich, England, and Elliot M. Meyerowitz of Caltech. The evidence for the model came from genes identified in two distantly related species, arabidopsis and snapdragon. (Arabidopsis is the plant biologist's counterpart to the zoologist's fruit fly, the most important plant studied in the laboratory as a model. In 2000 it became the first plant to have its genome sequenced.)

According to the *ABC* model, genes that, collectively, carry out three functions, *A*, *B*, and *C*, must all be active in the floral meristem to form the four kinds of flower organs. Genes that carry out function *A* act in the sepal and petal whorls of the meristem; genes that carry out function *C* act in the stamen and carpel whorls; and genes that carry out function B straddle the two, acting in the petal and stamen whorls. Thus, *A* genes form sepals, *A* and *B* genes together form petals, *B* and *C* genes together form stamens, and *C* genes form carpels [*see diagram on page 39*].

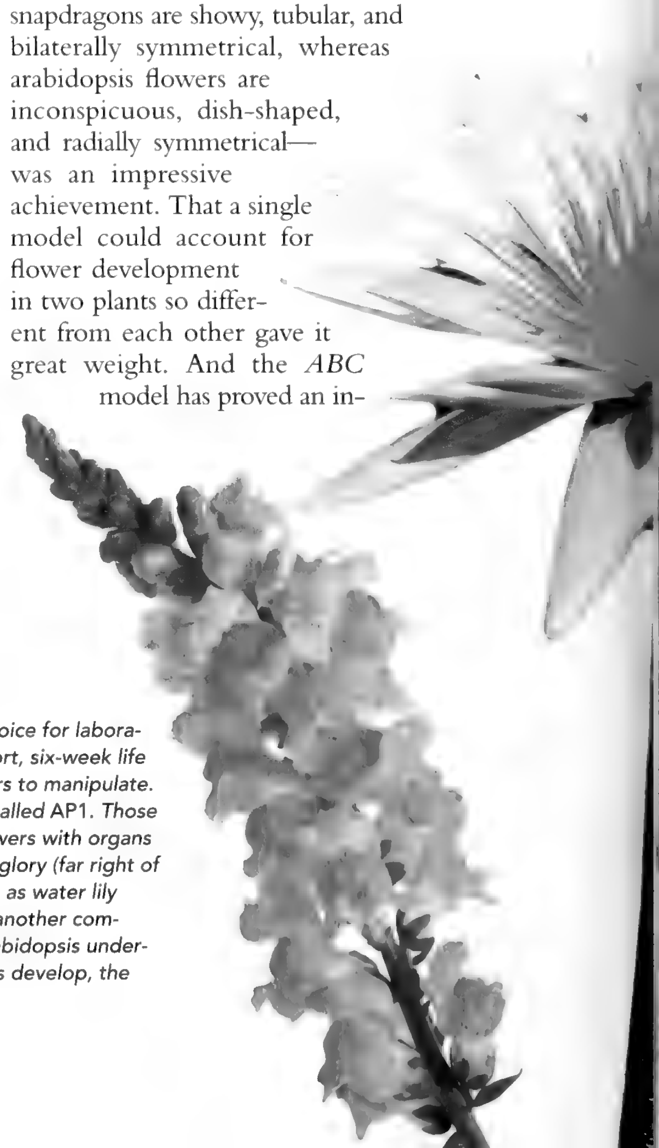
Oddly, the species that serves as an experimental model for the entire plant kingdom appears to be unique in the way it makes its flowers.

That's how the *ABC* model answers the evolutionary botanist's first question, What are the basic instructions for flower-organ formation? It also addresses parts of the second question: What are the variations in the instructions for diverse kinds of flowers? Although it does not explain variation in flower size, color, or symmetry, it does explain variation in flower form.

For example, the *ABC* model predicts that if a plant's *C* genes are inactivated, its *A* genes will become active throughout the developing meristem. With no *C* genes, stamens and carpels cannot form, but additional whorls of petals and sepals will take their place as the *A* and *B* genes exert their effects on the inner two meristem whorls. *C* genes also tell the flower to cease making new organs; without *C* genes, the pattern of sepal-petal-petal may repeat itself several times. That is exactly what takes place when the *C* genes in arabidopsis are experimentally inactivated. Cultivated roses and carnations, too, have extra whorls of petals in place of at least some of their reproductive organs, and plant biologists hypothesize that the change results from inactive *C* genes, in line with the *ABC* model.

Changes in the activity of *A*, *B*, and *C* genes have also been posited to explain other flower forms that don't conform to the standard sepal-petal-stamen-carpel construction. Lilies and tulips, for instance, have two whorls of petals instead of one whorl of sepals and one whorl of petals. The *ABC* model explains the double petals as a mutation in which *B* genes become active in the outer whorl of the meristem, where *A* genes usually act alone. When *A* and *B* genes both act in the outer two regions of the meristem, two whorls of petals form.

Explaining flower formation in two distantly related species with strikingly different flowers—snapdragons are showy, tubular, and bilaterally symmetrical, whereas arabidopsis flowers are inconspicuous, dish-shaped, and radially symmetrical—was an impressive achievement. That a single model could account for flower development in two plants so different from each other gave it great weight. And the *ABC* model has proved an in-

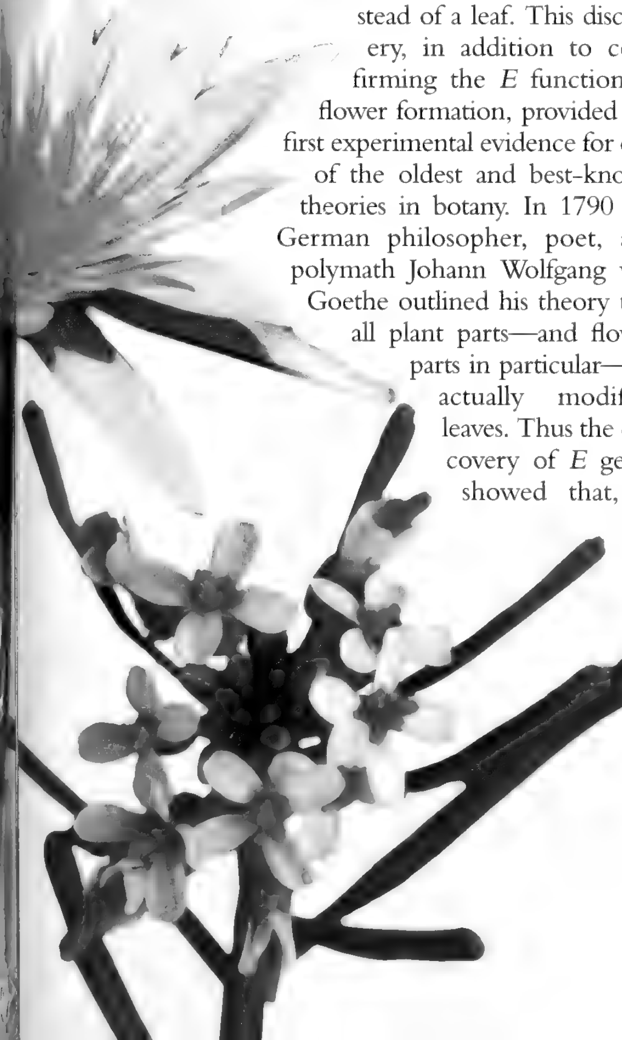


Arabidopsis thaliana *(rightmost flower at right) is the plant of choice for laboratory study, the "fruit fly" of the plant kingdom. Its small size, short, six-week life cycle, and simple genome make it relatively easy for investigators to manipulate. All plant species possess genes related to an arabidopsis gene called* AP1. *Those genes may have played an important role in the evolution of flowers with organs arranged in concentric whorls, such as arabidopsis and morning glory (far right of opposite page), from flowers with spirally arranged organs, such as water lily (center flower at right). Snapdragon (leftmost flower at right) is another commonly studied plant. Genetic evidence from snapdragon and arabidopsis underlay the first widely accepted genetic model of how flower organs develop, the* ABC *model. The flowers are not all shown to the same scale.*

valuable tool for analyzing the genetic basis of flower development in many other species, as well.

But as powerful and useful as the *ABC* model is, flower forms are more complicated than *ABC*. In recent years several discoveries have forced plant biologists to reevaluate the model. First, new genes were discovered that are necessary for flower organs to form, but that have a different function than *A*, *B*, or *C* genes. In 2000 Soraya Pelaz and Martin F. Yanofsky, both plant biologists at the University of California, San Diego, and several colleagues discovered three closely related genes (called *SEPALLATA*) in arabidopsis that were needed for petals, stamens, and carpels to form. Without the *SEPALLATA* genes, sepals grow in all four flower whorls. The investigators designated the new function *E* (*D* had already been applied to an aspect of ovule formation), and concluded that *E* genes join *A*, *B*, and *C* genes as the parties responsible for forming the inner three flower whorls.

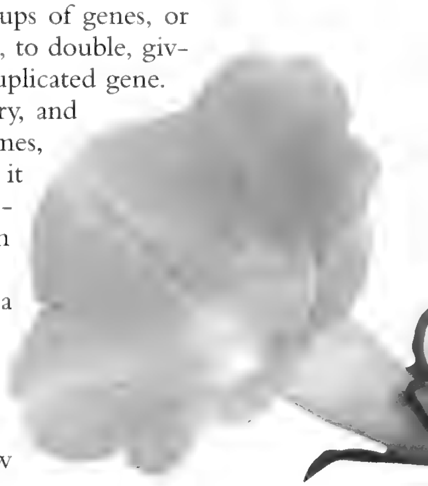
Then, in 2001, Takashi Honma and Koji Goto, both plant biologists at Kyoto University in Japan, discovered that when *A*, *B*, and *E* genes are all activated during leaf development, a petal forms instead of a leaf. This discovery, in addition to confirming the *E* function in flower formation, provided the first experimental evidence for one of the oldest and best-known theories in botany. In 1790 the German philosopher, poet, and polymath Johann Wolfgang von Goethe outlined his theory that all plant parts—and flower parts in particular—are actually modified leaves. Thus the discovery of *E* genes showed that, as Goethe aphorized two centuries ago, "Alles ist Blatt" (all is leaf).



Another challenge to the *ABC* model is its failure to identify genes that perform function *A* in species other than arabidopsis. *B*, *C*, and *E* genes, however, have been confirmed in other species. Oddly, the species that serves as an experimental model for the entire plant kingdom appears to be unique in having *A* genes (a condition it most likely shares with other members of the mustard family). Why should that be so?

The evidence points to a phenomenon known as gene duplication. Throughout evolution, it has been extremely common for groups of genes, or even an organism's entire genome, to double, giving rise to two copies of every duplicated gene. The copies are usually unnecessary, and often they are simply lost. Sometimes, however, the "new" copy, since it serves no critical function, can accumulate mutations, or random changes, in its DNA sequence.

Most of the mutations render a gene copy useless, or even harmful, but in some cases they give a gene new capabilities. Occasionally, they may even bring about profound changes—perhaps a new flower form, or even a brand-new species. Over time, in fact, gene duplication has provided the genetic raw material for the evolution of diversity and complexity. The *A*, *B*, *C*, and *E* genes, for instance, have all undergone multiple duplications during their evolutionary history. Since these genes are transcription factors that turn molecular cascades on and off, their duplications may have been particularly important in the evolution of new flower forms.



Morning glory

Duplications in the evolutionary history of the *A* genes may explain why arabidopsis (and probably other mustards) is alone among flowering plants in having *A* genes. When an *A* gene called *APETALA1* (*AP1* for short) is experimentally inactivated, stamens and carpels form normally. But instead of sepals, modified leaves grow, and instead of petals, there are branches bearing additional unusual flowers. The pattern of branching flowers growing from other branching flowers repeats several times.

The role of *AP1* in forming sepals and petals in arabidopsis is largely responsible for introducing the concept of *A* genes. In other species, genes homologous to *AP1*—genes, that is, that share a common ancestor with *AP1*—do not perform the same role. Even in the snapdragon, the other species on which the *ABC* model was based, the *AP1* homologue,

which is called *SQUAMOSA,* does not carry out function *A*. Inactivating the *SQUAMOSA* gene leads to fewer flowers and more inflorescence branching in the snapdragon, but it does not interfere with the formation of sepals or petals.

Why should *AP1* in arabidopsis act differently than its homologues do in other species? Vivian Irish and I examined *AP1, SQUAMOSA,* and their homologues in fifty-four disparate angiosperm species, then constructed an evolutionary tree of all the homologues. The tree showed at what point gene duplications had taken place during the evolution of flowering plants, much the way the evolutionary tree of a family of animal or plant species shows at what point new species arise.

We discovered that an important genetic duplication had taken place in a large assemblage of related species called the core eudicots. Many familiar plants belong to the core eudicots, including arabidopsis, daisies, oaks, roses, snapdragons, and tomatoes. Because of the gene duplication, all the species of core eudicots carry *AP1* homologues that belong to two groups; for simplicity, I'll call them group X and group Y. The *AP1* gene of arabidopsis and the *SQUAMOSA* gene of the snapdragon belong to group X. The other homologues fall into group Y, in which we also discovered a second doubling. That brings the total number of predicted *AP1* homologues in the genome of each species of core eudicots to three: one homologue from group X and two from group Y.

But the mustard family, including arabidopsis, is different from other eudicots. Mustards, it seems, have lost one gene from group Y, and duplicated *AP1* itself, the gene from group X. Thus, arabidopsis still has three *AP1* homologues, like the other core eudicots, but two belong to group X and only one belongs to group Y. Because copies of genes can take on new roles, it is likely that the group X genes and the group Y gene in arabidopsis have divvied up the tasks of flower formation differently than the three *AP1* homologue genes have in other core eudicots. That probably explains why *AP1* acts differently in arabidopsis than its homologues do in other species.

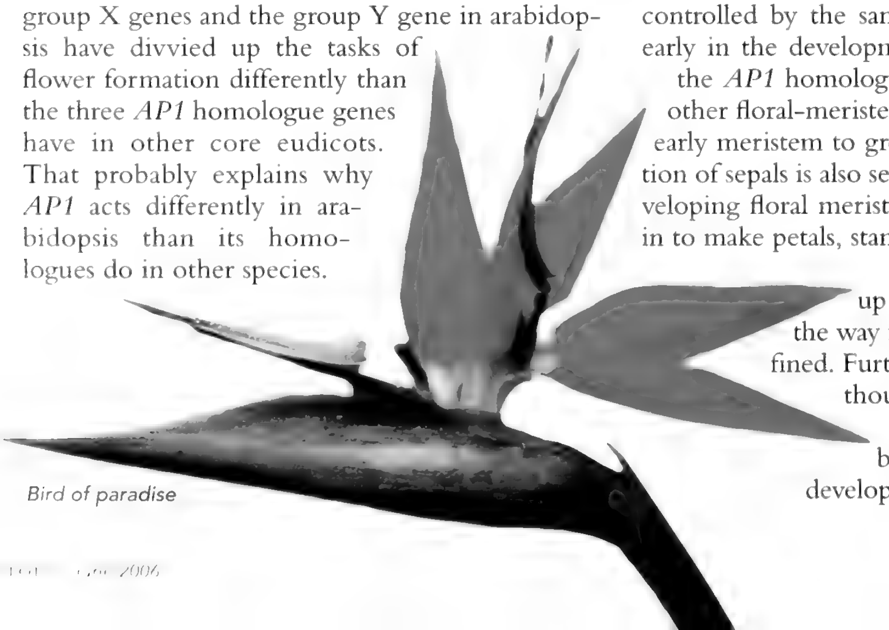
Thus, the evolutionary history of the *AP1* homologues shows that the *A* part of the *ABC* model may exist only in the mustard family. But a closer look at the evidence suggests that the *A* part may not even exist there. The *AP1* gene in arabidopsis performs not just the official role ascribed to *A* genes, forming petals and sepals. *AP1* also plays a more basic role, one that is outside the scope of the *ABC* model: directing the meristem to form a flower. Recall that, as I mentioned earlier, when *AP1* is experimentally inactivated, leaves and branches form instead of sepals and petals. The resulting structure resembles a branched inflorescence more than it does a flower.

The other two *AP1* homologues in arabidopsis also share in directing the meristem to form a flower. For example, if *AP1* and the other gene belonging to group X, which is called *CAULIFLOWER,* are inactivated, flowers just don't form. Instead, the inflorescence proliferates a dense head of branches, like a tiny cauliflower. In fact, a study of cultivated cauliflower (also a member of the mustard family) has shown that a defect in its homologue of the *CAULIFLOWER* gene is probably responsible for the characteristic dense white curds.

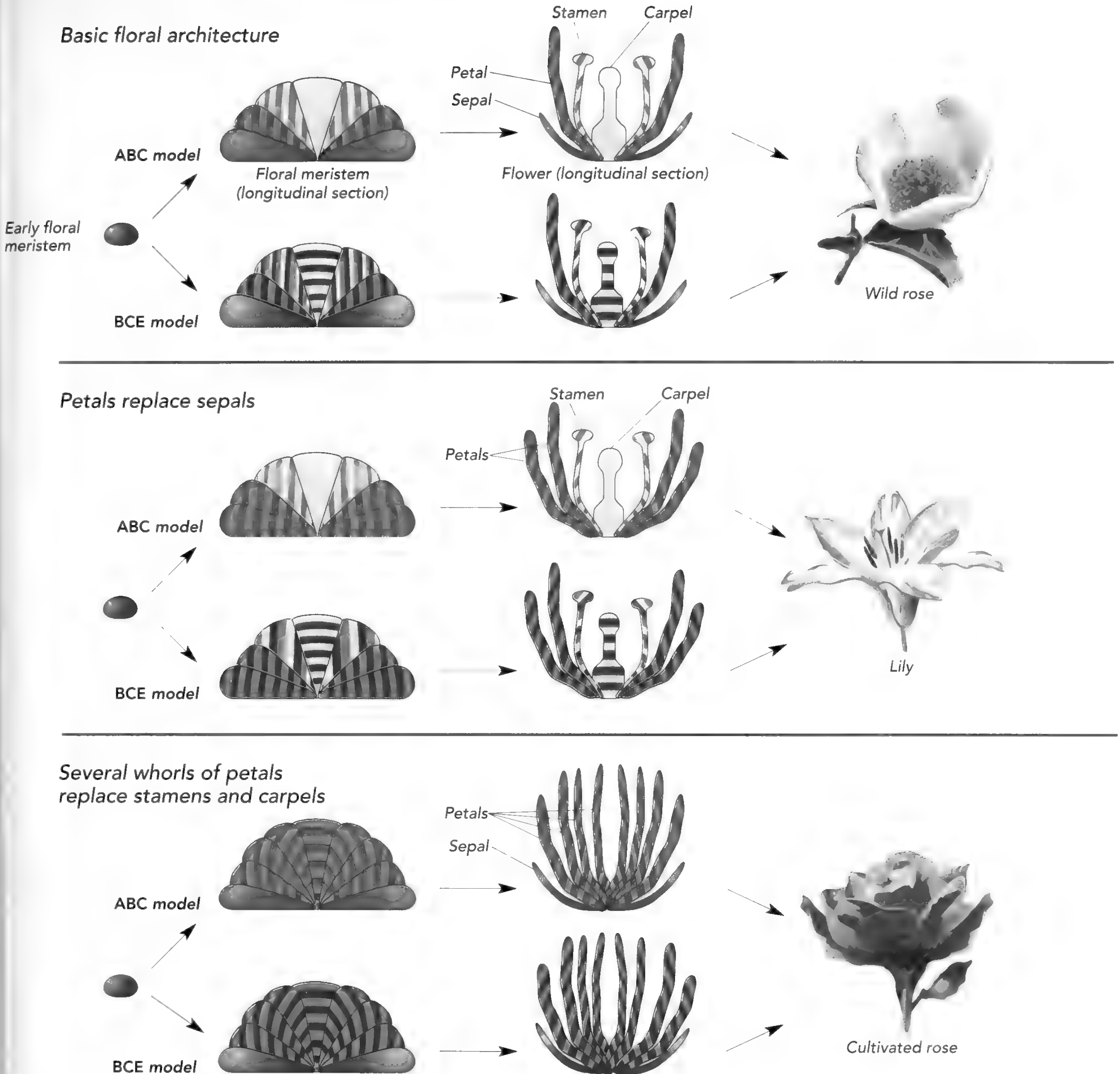
In species outside the mustard family, when *AP1* homologues are inactivated, only the sepals, and not the petals, often fail to form properly. But in nearly all species, the inactivation reduces flowering and increases branching. That finding is strong evidence that the fundamental role of *AP1* homologue genes is helping direct the flower to form in the first place—not directing sepal and petal formation. *AP1* homologues are therefore more accurately described as floral-meristem-identity genes—genes that direct a meristem to become a flower.

In fact, it appears that whenever sepals fail to form properly, flowering itself is reduced. Forming flowers and forming sepals, therefore, seem to be controlled by the same *AP1* homologues, acting early in the development of the meristem. Once the *AP1* homologues (with the help of several other floral-meristem-identity genes) instruct an early meristem to grow into a flower, the formation of sepals is also set in motion. Later, in the developing floral meristem, *B, C,* and *E* genes kick in to make petals, stamens, and carpels.

In short, no genes divvy up the developmental work in the way function *A* was originally defined. Furthermore, the genes that were thought to provide function *A* act well before the organs begin to specialize, during a developmental stage that the model



Bird of paradise



ABC model of flower-organ development is contrasted with the proposed BCE model, in this schematic diagram of the genetic blueprint for three common flower forms. According to the ABC model, genes with three different functions (A, B, and C) act in concentric rings, or whorls, of cells within a floral meristem. (A floral meristem is a mass of undifferentiated cells that grows into a flower; it is not depicted to scale in the diagram.) The genes that act in a given whorl of a floral meristem determine which kind of organ (sepal, petal, stamen, or carpel) the whorl grows into. In the ABC model, genes with function A in the outer whorl build sepals; A and B genes in the second whorl produce petals; B and C genes in the third whorl produce stamens; and C genes in the center of the meristem produce carpels. Botanists think that flowers such as lilies, with a set of petals instead of sepals, result from a mutation in which B genes act in the meristem's outer whorl. Flowers with several sets of petals instead of stamens and carpels, such as cultivated roses, are thought to result from a mutation that makes C genes inactive. Recently another set of genes was identified that is necessary for the growth of petals, stamens, and carpels: genes with the so-called function E. That discovery, along with evidence that casts doubt on the very existence of function A, has called the ABC model into question. The proposed BCE model posits that sepals form under the direction of the same genes that tell early meristems to grow into flowers: the floral-meristem-identity genes.

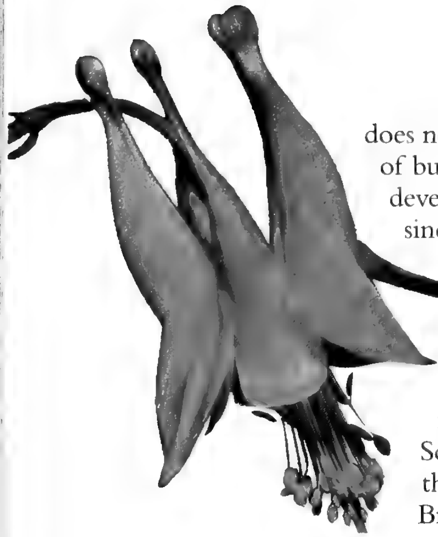
Function A genes

Function B genes

Function C genes

Function E genes

Floral-meristem-identity genes



Columbine

does not address. Since the function *A* job of building both sepals and petals in the developing meristem does not exist, and since *E* genes are now known to be necessary for flower organs to form, the *ABC* model gets rewritten as *BCE*.

It is worth mentioning that in 1990, shortly before the *ABC* model was published, Zsuzsanna Schwarz-Sommer, a plant biologist at the Max Planck Institute for Plant Breeding Research in Cologne, Germany, and several colleagues published a two-gene model of flower formation. Those two genes have since been designated *B* and *C* genes. Although it received considerably less attention at the time than the *ABC* model, Schwarz-Sommer's theory clearly anticipated the *BCE* model in recognizing that no special gene function was needed for sepal formation.

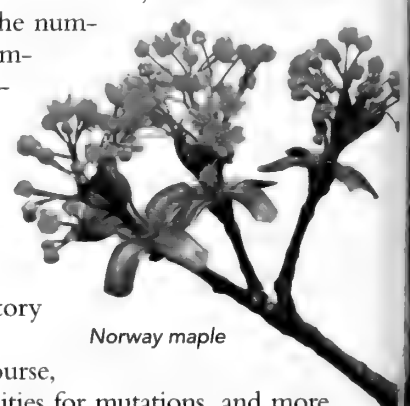
Although *AP1* homologues may not play exactly the same role of sepal- and petal-building in the meristem for which *AP1* became well known, it is likely that they have had other important roles in floral evolution. The duplication that gave rise to group X and group Y in the core eudicots may have been important in standardizing flower construction. In some species that are more ancient than the core eudicots, such as magnolias or water lilies, flower parts are arranged in one continuous spiral. Some spiral flowers, such as water lilies, have transitional organs that are partway between a sepal and a petal, or between a petal and a stamen.

But within the core eudicots, flowers arrange their parts in discrete, concentric whorls, and none have transitional organs. It was probably the whorled arrangement that led to the tremendous floral elaboration and innovation in the core eudicots (not to mention other plant groups with whorled flowers). Whorled flowers simply have more evolutionary flexibility than spiral flowers. Whorled flowers can abandon the radial symmetry of arabidopsis for the bilateral symmetry of snapdragon. Whorled petals can fuse to form tubes, as in morning glory, and stamens can fuse to petals, as in mint flowers. New organs, such as the colorful filaments between the stamens and petals of a passionflower, can arise between whorls.

In arabidopsis, *AP1* is required for the transition from a branched inflorescence, whose branches bear spirally arranged leaves, to a flower, which bears whorled parts. The duplication that gave rise to group X and group Y, followed by the acquisition of new functions in group X, may likewise have provided the genetic instructions for whorled flowers in the core eudicots—and set the stage for the explosion of flower forms within this group.

Even earlier, *AP1* homologues, as well as *SEPALLATA* homologues (the *E* genes), may have played a role in the origin of the first flower around 150 million years ago. Charles Darwin called the origin of the flower an "abominable mystery," and it stumps evolutionary botanists to this day. Gymnosperms have *B* and *C* genes, which help build the male and female parts of their reproductive cones. When the first angiosperm evolved from the gymnosperms, it most likely incorporated *B* and *C* genes into its flowers. But no *AP1* or *SEPALLATA* homologues have been detected in gymnosperms—they appeared when the flowering plants appeared. Those two gene lineages are closely related, and probably arose via gene duplications that took place within a short time period. Since *AP1* homologues are required for a meristem to form a flower, it's conceivable that they assisted in the evolution of the first flowers.

Genes account for the stunning diversity of form and function among flowers—and in the natural world at large, for that matter. Plants and animals have many more genes than do simpler organisms: both arabidopsis and people have about 25,000 genes, compared to the 3,000 in bacteria. Much of the rise in the number of genes that accompanies increasing complexity, it is now becoming clear, arose from duplications in all or part of the genome. Such duplications have peppered the evolutionary history of most organisms.



Norway maple

More genes, of course, imply more opportunities for mutations, and more opportunities for new forms and functions to evolve. Moreover, when the genes in question are transcription factors, the entire form or life cycle of an organism can be altered. Evolutionary botanists are still working out most of the details in the quest to account for today's floral diversity. All flowering plants rely on a shared set of fundamental gene functions to build their blooms. But the evidence is mounting that gene duplication has played the pivotal role in creating arabidopsis, lily, rose, snapdragon, and the 250,000 other members of Earth's great floral bouquet. □

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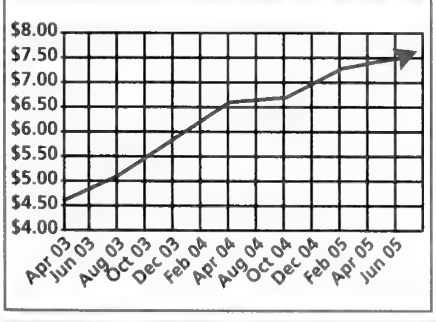

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This Old House

At Çatalhöyük, a Neolithic site in Turkey, families packed their mud-brick houses close together and traipsed over roofs to climb into their rooms from above.

By Ian Hodder

Every summer since 1993 I have returned to central Turkey to work on the archaeological excavation of a mound nearly seventy feet high. As I tread over its soil, I feel a tingling in my feet, knowing that buried beneath me are the abundant remains of a town inhabited from 9,400 until 8,000 years ago. Rising just 500 feet to my west is a second, smaller mound, which was occupied from about 8,000 until 7,700 years ago. The archaeological site made up of the two mounds is still no more than 5 percent exposed. Until the digs began, an old footpath made a fork at the mounds, and so the larger one became known locally as Çatalhöyük (pronounced approximately *cha-tal-HU-yuk*), which means "fork mound." The archaeological site has adopted that name.

Wall painting, some 8,500 years old, was discovered by the English archaeologist James Mellaart in the 1960s, during his excavations of the Turkish site of Çatalhöyük. In Mellaart's interpretation of the painting, the foreground shows a town, possibly Çatalhöyük itself, with the eruption, in the background, of a twin-peaked volcano, perhaps Hasan Dağ (see map on page 44). Mellaart's reconstruction of the painting appears at the top of this page.

Çatalhöyük was first identified and excavated in the late 1950s and early 1960s by the English archaeologist James Mellaart. His excavations revealed fourteen levels of occupation in the larger mound, created as people tore down old houses, filled them in, and built new ones on top. Altogether, Mellaart excavated about 160 buildings, spread over the various levels. Each building probably housed a family of between five and ten people. One main room was the locus of family living, cooking, eating, craft activities, and sleeping, and there were side rooms for storage and food preparation.

Mellaart's excavations turned up evidence that the people of Çatalhöyük made use of domesticated plants and animals. The finding excited wide interest, because it meant that very early farming villages

grew up not only in the Levant and adjacent areas of the Middle East, where wild plants and animals were first domesticated, but also here, in Anatolia. But even more astonishing were some other distinctive characteristics of Çatalhöyük that Mellaart was the first to describe. The houses of Çatalhöyük were so tightly packed together that there were few or no streets. Access to interior spaces was across roofs—which had been made of wood and reeds plastered with mud—and down stairs. People buried their dead beneath the floors. Above all, the interiors were rich with artwork—mural paintings, reliefs, and sculptures, including images of women that some interpreted as evidence for a cult of a mother goddess.

Çatalhöyük was quite large for a town of Neolithic age—the time from about 11,500 to 8,000 years ago, when people began living in relatively permanent villages and making use of domesticated crops and animals. The population fluctuated between 3,000 and 8,000; in physical area the large mound encompassed some 33.5 acres. Unsurprisingly then, despite excavating for four years, Mellaart uncovered only a small part of the town. The current dig, which I direct, has excavated or determined the outlines of eighty more buildings and has identified four additional levels of occupation in the larger mound. Yet as I walk over that mound, I am well aware that thousands of buildings are still hidden beneath the soil, full of art and symbolism, waiting to be explored.

Archaeologists do know a lot more now than they did at the time of Mellaart's discovery about other Anatolian settlements dating from the Neolithic. But for any student of that era—myself included—Çatalhöyük and its mysteries hold a special appeal. What led to the concentration of art in so many houses at one site? Why was the settlement so large—what drew people to that particular place? And how much can be learned from what is perhaps the most intriguing feature of all about Çatalhöyük: that the site was built and rebuilt over the centuries in ways that provide an unusually rich record of the minutiae of daily life?

The main reason for the abundance of the archaeological record was that the Çatalhöyükans used a particular kind of construction material. Instead of making hard, lime floors that held up for decades (as was the case at many sites in Anatolia and the Middle East), the inhabitants of Çatalhöyük made their floors mostly out of a lime-rich mud plaster, which remained soft and in need of continual resurfacing. Once a year—in some cases once a month—floors and wall plasters had to be resurfaced. Those thin layers of plaster, somewhat like the growth rings in a tree, trap traces of activity in a well-defined temporal sequence. The floors even preserve such subtle tokens of daily life as the impressions of floor mats. Middens are just as finely layered, making it possible to identify details as subtle as individual dumps of trash from a hearth.

When a house reached the end of its practical life, people demolished the upper walls and carefully filled in the lower half of the house, which then became the foundation for new walls of a new house. The mound itself came into being largely through such gradual accumulation. Taking it apart enables us to revisit the past.

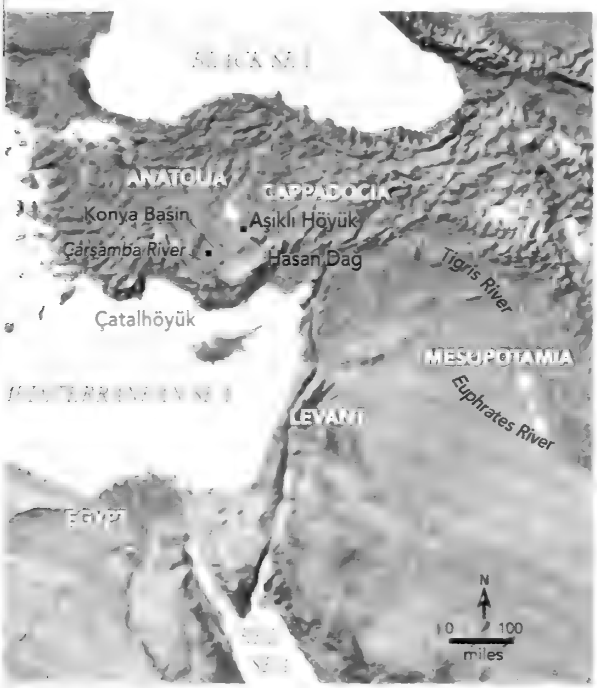
Çatalhöyük lies in the Konya Basin, which in Neolithic times was mostly a semiarid plain with steppe vegetation: grasses, sedges, and small bushes [*see map on next page*]. The soil, the residue from a vanished lake, was made up of marls—deposits of clay with high levels of calcium carbonate. Its consistency and low nutrient value made the soil unsuitable for early forms of agriculture. The basin, however, included some marshy areas, several rivers, and, perhaps, some small, shallow, seasonal lakes. In any event, there were deposits of alluvial soil that were more hospitable than the marls to early farmers and herders.

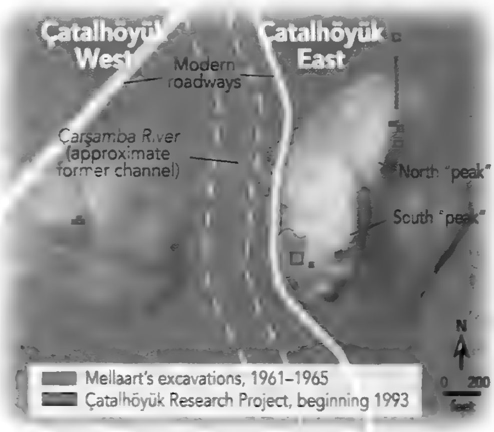
One of the rivers in the Konya Basin was the Çarşamba, which spewed out into the plain and did

Excavations of the East Mound of Çatalhöyük, done by Mellaart in the 1960s, show that the buildings on the 33.5-acre mound were packed close together, without intervening streets or alleyways. Access to house interiors was originally across the roofs and down a stairway.

not link to any other river system. Çatalhöyük was founded on its east bank, most likely on a small existing rise. (The river no longer runs by the site, having been diverted into irrigation channels.) The site would have been surrounded by marshy swamps in the spring, the results of the river's seasonal flooding.

Those observations partly explain the original siting of the town: Çatalhöyük was built where it was because, in a semiarid environment, people sought access to water and to soils as rich as possible in nutrients. But in that context, one of our recent findings carries surprising implications.





Site of Çatalhöyük, located in the semiarid Konya Basin of Anatolia (now central Turkey), comprises two mounds that accumulated as the settlement's inhabitants repeatedly built, tore down, and rebuilt their mud-brick houses. The eastern mound, dating from 9,400 until 8,000 years ago, has two "peaks," suggesting that the population may have been divided into two intermarrying kin groups. The western mound was occupied from about 8,000 until 7,700 years ago.

To learn where the crop plants found at Çatalhöyük were grown, we examined the evidence for phytoliths—silica skeletons that form inside and sometimes around the cells of grasses and other plants. Grasses that grow in moist, clay-rich soils have more soluble silica available for forming phytoliths than do grasses that grow in well-drained, dry-land soils. As a result, large, composite phytoliths form in grasses from moist, clay-rich soils, built up from as many as a hundred or more adjacent cells. Given the ground conditions around Çatalhöyük, we expected to see evidence of such large phytoliths. But a sample of wheat-husk phytoliths studied by Arlene Rosen, an archaeologist at University College London, showed relatively few multicell clusters, suggesting that the wheat was cultivated in dry-land soils—and so not near the mound. Thus at least some of the agricultural fields appear to have been placed well away from the site.

That finding suggested the question "why here?" might require a more complex answer. The wet marshes surrounding Çatalhöyük would certainly have offered a wide range of wild food resources, from fish and the eggs of waterfowl (both of which have been found on the site) to wild cattle and other mammals attracted by the water and by the fresh graze that grew on the alluvium. Another attraction of the site might have been ready access to construction materials, which included the reeds people weaved into matting and incorporated into roofing and the mud made into bricks and plaster. In one area we excavated to the north of the large mound, we discovered many pits where the inhabitants had cut through a thin layer of alluvium in order to extract the underlying lime-rich marls. Fragments scattered in the middens show that in the earliest levels of the site, floors were constructed out of hard, fired-lime plaster, but in later levels, the softer lime-rich mud plaster makes its appearance on the walls and floors. Firing lime requires a lot of fuel, and my guess is that the process became impractical because local sources of wood were used up.

In fact, there is good evidence that the Çatalhöyükans engaged in long-distance trade. Date-palm phytoliths at the site indicate that storage baskets were brought to Çatalhöyük from Mesopotamia or the Levant; shells suggest trade from the Red Sea and the Mediterranean; obsidian undoubtedly came from Cappadocia, a region about ninety miles to the northeast; oak and other timber must have come from at least as far as the nearest upland, six miles away. But the Çatalhöyük economy was still primarily a subsistence one. The Çatalhöyükans grew their own cereals, such as emmer wheat, and legumes, such as peas and lentils; they raised their own sheep and goats; and, to a lesser extent, they hunted wild cattle.

Archaeologists today automatically assume that people cluster at a site not only for proximity to resources, but also for social reasons. For example, people may want to organize their labors, take part

in community-wide rituals, or provide for defense against a common enemy. And some sites in Anatolia, earlier than Çatalhöyük, clearly emphasize that collective spirit. Art is concentrated in special ritual buildings, houses are laid out in zones, and human skulls are sometimes buried communally.

In contrast, a good case can be made that many aspects of life at Çatalhöyük were organized at the domestic, or household, scale. Brian F. Byrd, an archaeologist with the Far Western Anthropological Research Group in Davis, California, has noted that during the Neolithic there was a general shift in the southern Levant toward greater autonomy and complexity at the household level. A similar historical shift can be readily traced in central Anatolia. For example, at Aşıklı Höyük, a site dating from about 10,700 until 9,300 years ago, there are ceremonial buildings, but the houses are much less elaborate than the ones at Çatalhöyük, where a wide range of functions, from burial, ritual, and art to storage, manufacture, and production were more clearly drawn into the house.

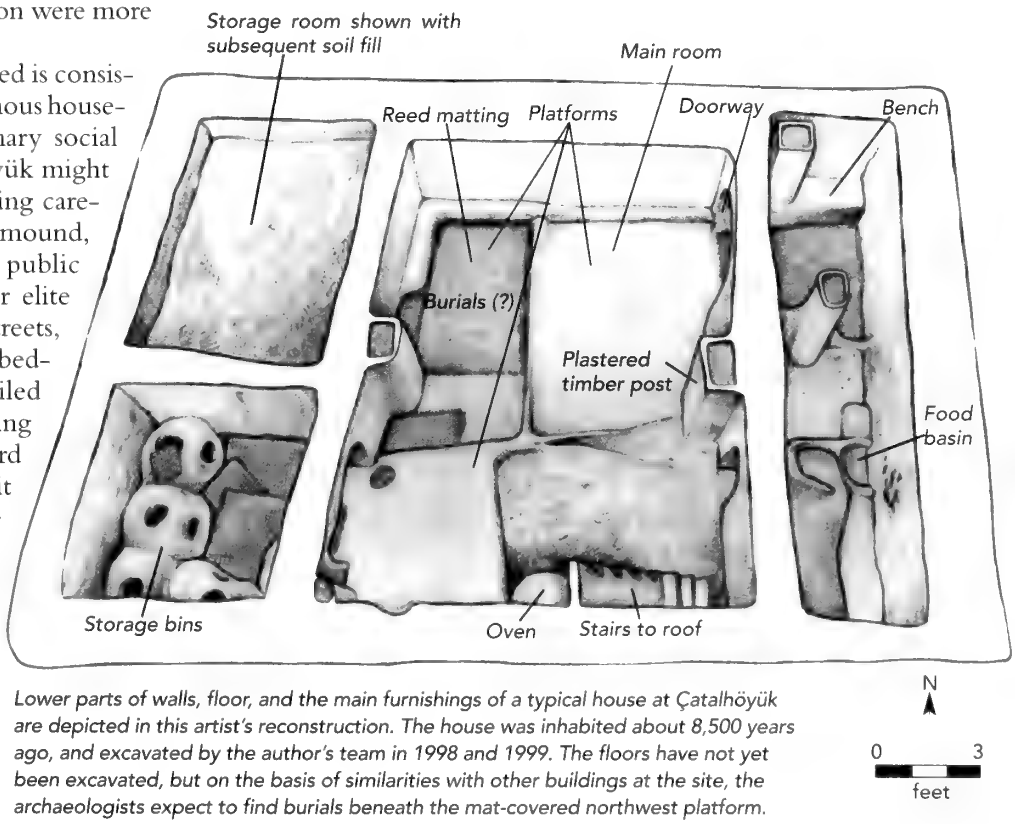
Other evidence we have assembled is consistent with the view that the autonomous household at Çatalhöyük was the primary social unit. In size, for instance, Çatalhöyük might have been a town, but despite taking careful samples from the surface of the mound, we have found no evidence for public spaces, administrative buildings, or elite homes or quarters. There were no streets, and in fact the buildings were embedded in extensive midden areas piled with trash, fecal material, and rotting organic material—not at all in accord with modern sensibilities. Perhaps it is little wonder that access to the houses was along the roofs and down some stairs!

The autonomy of the Çatalhöyük household is also reflected in how rarely two buildings shared a wall: even though houses might be just a few inches apart, people built and maintained their own walls. Each house was built with bricks of distinct composition or shape. The bins in the houses suggest they all had a similar storage capacity for agricultural produce. And each house seems to have had its own hearth, oven, obsidian cache, storage rooms, work rooms, and so on, for the inhabitants' own activities.

Yet despite the central role of the individual household, my colleagues and I see hints that Çatalhöyükans were divided into two large groups throughout most of the time it was occupied. The contour of the larger mound reveals two built-up areas, a northern one and a southern one, with a gully between them. A possible explanation is that Çatalhöyük was an endogamous culture, or in other words, people married within the settlement. It may have been organized, as are many other traditional societies, into two intermarrying kinship groups. Surveys in the plain around Çatalhöyük have turned up earlier and later sites, but none of them seem to have flourished at the same time—further evidence that marriage was probably a local affair.

The standard house had one main room, which accommodated an oven, a burial platform, and other platforms [*see illustration below*]. One or more side rooms served as storerooms, kitchen, and places for other domestic tasks. The stairs from the roof entrance—perhaps made of a log with steps notched in it—led into the main room. Walls were built of mud bricks and were windowless. On average, they were 1.3 feet thick and stood eight to ten feet high. The interior walls, floors, and posts for the roof were all plastered.

So far we have identified two kinds of cooking fires in Çatalhöyük: domed ovens were set into house walls, and hearths stood away from the walls.



Lower parts of walls, floor, and the main furnishings of a typical house at Çatalhöyük are depicted in this artist's reconstruction. The house was inhabited about 8,500 years ago, and excavated by the author's team in 1998 and 1999. The floors have not yet been excavated, but on the basis of similarities with other buildings at the site, the archaeologists expect to find burials beneath the mat-covered northwest platform.

Skull of a male (top right), whose features had been repeatedly modeled in plaster and painted, is shown in an artist's reconstruction. The skull was recently discovered in the burial of a female (photograph above); it may have belonged to a revered ancestor or relative of the deceased. The placement of the skull with respect to the female skeleton is shown in red outline in the diagram at right.

Collections of clay balls were often associated with the ovens. According to research by Sonya L. Atalay, an archaeologist at Stanford University, the balls were used in cooking—just as, in many traditional societies, heated stones were put in a basket or skin container to boil water, or laid out to cook meat. Because stones are in short supply at Çatalhöyük, the clay balls served the same purpose. At later levels, pottery containers, which could be placed directly over a fire, took over the heating function.

In the houses excavated so far, hearths and ovens were generally placed on the south side of the main rooms. In those areas the floor is blackened by the ash and charcoal raked out from the fires. Manufacturing activities were probably carried out there: we find evidence on the floors that obsidian was knapped, or chipped, into tools, that beads were made, that grease was extracted from animal bones. Obsidian caches, as well as depressions for holding pots and other small stores, were often built below the floors. Little or no art appears in this "dirty" zone of the main room, and the only burials here seem to have been the bodies of newborns or infants.

In contrast, the plaster floors and platforms in the rest of the main room are lighter in color, and sometimes even white. Ridges or platform edges often separate this area from the "dirty" zone. The "clean" areas often have higher platforms and more painting, and they are where burials were commonly made.

What points most to a household level of social organization is the rich symbolic content of the houses. Paintings depict vultures flying over headless human bodies, suggesting the practice, adopted in some parts of the world, of setting out the deceased so that they can be naturally defleshed. Figurines depict generously proportioned females. One sculpture shows a female seated on a "throne" whose armrests are felines [*see photograph on opposite page*]. Recently we unearthed a male skull, perhaps belonging to a revered ancestor, over which plaster features had been periodically modeled and painted. Eventually another person died—a female—and the skull was buried along with her [*see photograph and illustrations at left*].

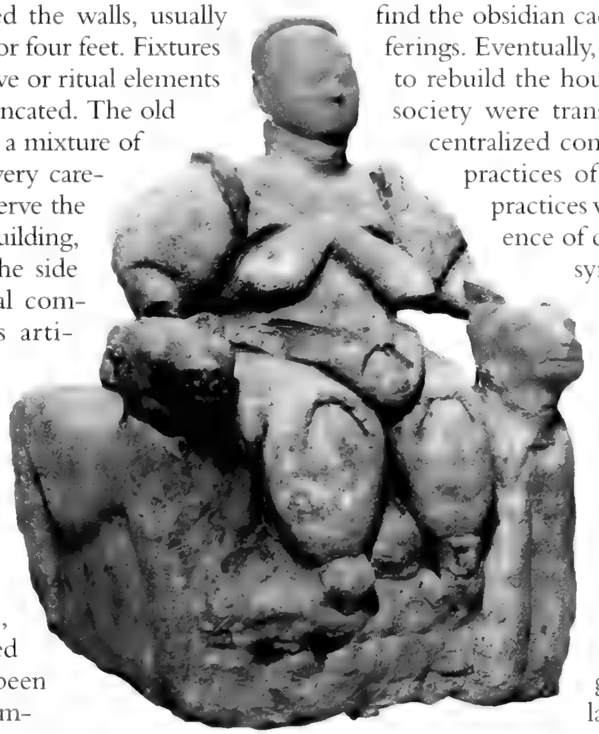
What particularly fascinates me are the many leopard motifs, including reliefs of paired leopards. The images suggest that a relationship with wild animals was a potent element in local religious ritual and belief. In line with that interpretation, the household shrines often incorporate the horns of a wild bull. In contrast, the ancient artists neglected to represent most of the more mundane activities, such as the growing of crops. The emphasis on certain themes in the art appears significant, but from our distant vantage point, we can only glimpse how the people of Çatalhöyük interpreted the world around them.

Mellaart thought that some of the buildings in the settlement, because of their decorative and symbolic contents, might have been specialized shrines. We now understand them all as houses, but with varying degrees of ritual elaboration. In the plastered floor of what we call Building 1, for example, we discovered a complete fishhook pendant made from a split boar's tusk, apparently placed there intentionally. A small plaster sculpture in the shape of an animal horn was inserted in one wall of the main room. We also found that two holes had been dug into the walls and then plastered over; we think they were made to contain objects that were later removed. A small fragment of a figurine made of animal horn was embedded in the material used to construct an oven in a side room. Perhaps those deposits were symbolically protective, or perhaps they represented memories, links with the past. We can't really say, but in general terms they show that construction integrated ritual and daily practice.

One clear result of the current excavations is the demonstration that most of the burials in the houses were of individual, fully fleshed bodies. Mellaart and his team had found jumbled, disarticulated human bones beneath the platforms in the main rooms. They assumed the bodies were initially buried elsewhere and then reburied beneath the platform floors. That idea was supported by the paintings of vultures apparently picking the flesh from headless human corpses. But our work shows that many bodies were

buried under the platforms intact: the joints are still articulated and the smallest bones (often lost in reburial) are present. The jumbled nature of the bones beneath some platforms, we have concluded, was the result of inserting later graves within the same platform, a frequent practice.

Perhaps the most telling evidence for the symbolic importance of the house in life at Çatalhöyük is the meticulous procedure the inhabitants followed when—for structural or other reasons—they decided a house had to be torn down and rebuilt. To prepare for rebuilding, workers first cleaned and scoured the walls and plaster features of the original house. Then they removed the roof, dug out the main support posts, and dismantled the walls, usually down to a height of three or four feet. Fixtures such as ovens and decorative or ritual elements were often removed or truncated. The old house was then filled with a mixture of building materials, often very carefully. For example, to preserve the dome of the oven in one building, soil was fed in through the side opening. The fill material commonly included various artifacts—bone points, hunks of obsidian, stone axes. How many such objects were ritual placements as opposed to accidental losses is not always clear, but there are patterns to the work. The enthroned female figurine with felines, which Mellaart discovered in a bin, seems to have been placed there for some symbolic motive.



Baked clay figurine, about eight inches tall, was discovered by Mellaart in a grain bin. It was probably deposited there as an offering or memento when, in preparation for rebuilding the house, the inhabitants tore down the upper walls and filled in the foundation. Mellaart restored the missing heads of the seated woman and one of her feline armrests.

Before the current project began excavating houses in 1995, I had assumed we would just dig down and find houses frozen in time, static entities rather like the ones I had seen represented in Mellaart's reconstructions. But what we really discovered were processes. The new excavations show how the inhabitants of Çatalhöyük were always tinkering with the internal details of their homes. The various areas of a house might have had prescribed differences in flooring, height, color, plaster, matting, and so forth. But there were also continual adjustments in the course of daily life, as the spaces were remade, reworked, moved, or used for different purposes.

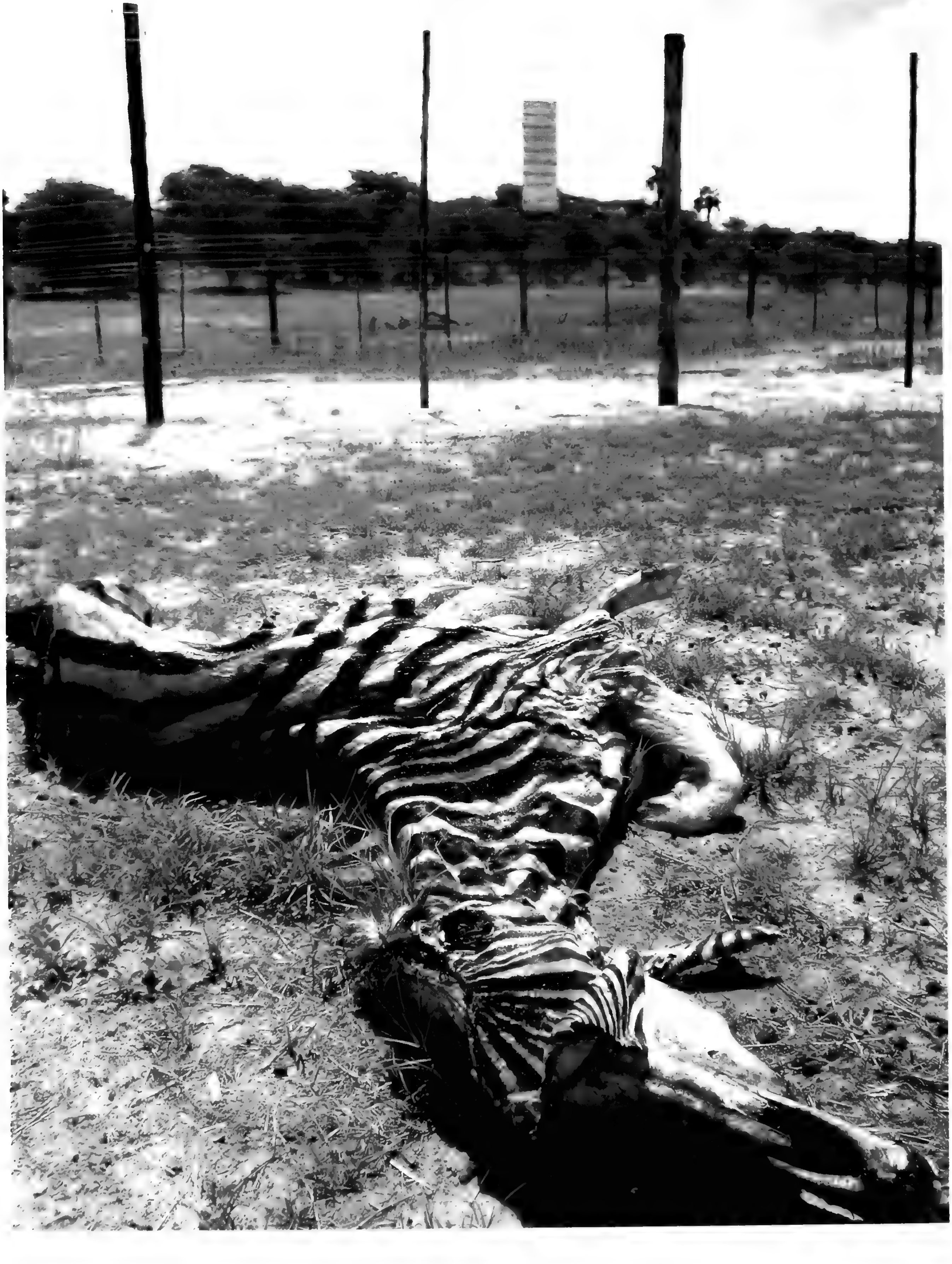
Can we begin to understand what it was like to live in the houses of Çatalhöyük? It is often said that they were dark inside. But an experimental house built at the site by Mirjana Stevanović, an archaeologist at the University of California, Berkeley, has shown that during the day so much light pours in from the stair entry that the main room is quite bright. Since the white plastered walls were so frequently renewed and often burnished, they reflected the light well. Even the side rooms got some reflected light; as one's eyes adjusted to the relative gloom, it would have been possible to carry out indoor activities.

A child growing up in such a household would soon learn how the space was organized—where to bury the dead and where to make beads, where to find the obsidian cache and where to place offerings. Eventually, he or she would learn how to rebuild the house itself. Thus the rules of society were transferred not through some centralized control, but through the daily practices of the household. All those practices were carried out in the presence of dead ancestors and within a symbolic world immediately at hand, conveyed through rich artistic representation.

But why such a large settlement should flourish precisely when and where it did still eludes us. Perhaps it enabled people to build up a network of relationships that would serve to control access to resources. Living close together meant that those relationships could be continually reinforced and monitored. By joining with others at the one site, each household could also better promote its own interests: finding marriage partners for its young people, developing exchange alliances, cementing links through ancestry, and so on.

But then again, we know that some evidence could suddenly emerge to suggest a quite different explanation. And so our excavations, and our informed speculations, will continue. □

This article has been adapted from Ian Hodder's forthcoming book, The Leopard's Tale: Revealing the Mysteries of Çatalhöyük, *which is being published this month by Thames & Hudson Inc.*



Good Fences, Good Neighbors?

Can Botswana simply cordon off the conflicts dividing ecotourism, cattle farming, and the interests of conservation?

By Graciela Flores

A few months into the construction of the 240-mile-long Makgadikgadi fence, David Dugmore drove along the first stretch of cable wire slung between vertical wooden posts. It was the dry season in north central Botswana, and Makgadikgadi Pans National Park, now bounded on the west by the fence, was stark and grim, its wildlife seemingly consigned to the dusty past. The seasonal drought from March through October had transformed the park into a lunar landscape shimmering with salt crystals—one of the largest salt pans in the world. But on this day, the austere beauty seemed more like a killing field. As he drove, Dugmore, the owner of a safari camp, counted zebra carcasses lining the fence. "There was at least one every kilometer," he recalls.

Roughly a hundred zebras died in a single month in 2004, before the fence was even completed. The zebras, on their annual migration to water holes and grazing areas to the west, had probably died from stress and dehydration when they met the new barrier. Others likely died in the jaws of hyenas or lions, which have learned to stampede zebras into the wire grids.

In one deadly week in 2005, some 250 zebras perished on their annual trek. Again, drought had forced them to search for water and grazing land, but again, the fence thwarted them. By the time the rains came, it was too late. "We were still removing dead animals from around the water hole as the grass grew around them, forming perfect outlines of their bodies lying in the sand," says Dugmore.

The Makgadikgadi fence is part of an intricate network of fences that crisscross thousands of miles of Botswana. Most of the fences were built to contain cattle and limit the spread of disease from wildlife to livestock—so-called veterinary fences. But the Makgadikgadi is not a veterinary fence; it is a "wildlife fence," the first of a new breed of fence designed to reduce conflicts between people and wildlife. Specifically, it was built to stop lions from attacking cattle, to stop villagers from retaliating against the lions, and to protect the grazing land of the wildlife in the park from the cattle. In short, its function was to balance the needs of a pastoral way of life centered around cattle raising with the needs of a rapidly growing tourism industry that depends on the wildlife.

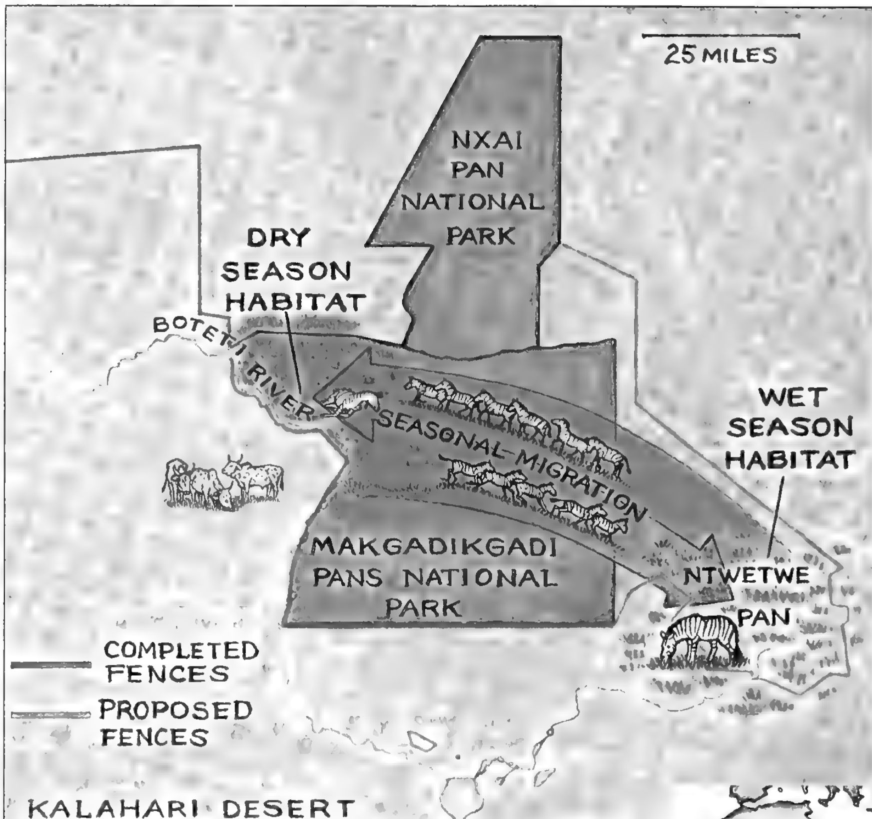
Hundreds of zebras, like the one in the photograph, have died because the Makgadikgadi fence, visible in the background, cuts off their annual migration route to dry-season water sources.

The government finished building the fence in 2004 and, indeed, it has largely solved the problems it was designed to solve. But the law of unintended consequences never rests, and the fence has spawned a host of new problems. Most troubling is that the fence is proving a deadly nemesis for wildlife. Today, eighteen months after its completion, the ambiguous nature of the Makgadikgadi fence continues to stir debate among conservationists, government agencies, and local communities.

Long before the fences, long before the government itself, the salt pans of Botswana were a massive inland lake. The lake dried out more then 2,000 years ago, leaving the salt pans in its place, but the region retained the two seasons of the tropics, dry and wet. The seasonal oscillation drives one of the largest annual migrations in Africa. Every year, when the pans dry up, the animals retreat, seeking refuge among the water holes to the west. In Setswana, the national language of Botswana, Makgadikgadi means "vast, open, lifeless land." The term could hardly describe the pans more accurately, at least in the dry season.

When the rains come, though, the pans exploded with life. The herds of herbivores and their predators return from their dry-season retreats to fill the surrounding grasslands. Thousands of flamingos and pelicans and a rich array of rare birds flock into the sanctuary. The pans in flood are no less dramatic. From 4,000 feet up, they look like a handful of sapphires set in the grasslands between the parched Kalahari Desert in the south and the lush waterways of the Okavango delta in the north.

Overlain on that natural setting is modern Bo-



Makgadikgadi Pans National Park lies in north central Botswana. The fence along the Boteti River, on the park's western border, was completed in 2004. Because of years of drought, however, most of the water in the Boteti channel lies underground. Thus thousands of zebras in the park that migrate during the dry season can no longer drink from the river, but the fence also virtually seals them off from any other water sources to its west. When the rains come, the zebras return east. The Botswana government plans to extend the fence to the park's eastern border.

tswana: like much of the rest of Africa, a land of social and economic contrasts. Since gaining its independence from the U.K. in 1966, the country has maintained one of the highest rates of economic growth in the world, as well as soaring rates of poverty and unemployment. The economy is largely based on diamond mining, tourism, and cattle farming, which is itself a source of great inequality. Large cattle producers—the "beef barons"—account for only 15 percent of the farmers in Botswana, yet they own 75 percent of the country's estimated 3 million head of cattle. Even for subsistence farmers, however, livestock are a source of social prestige. Although beef brings in just 3 percent of the gross domestic product (GDP), it remains a critical industry because cattle farming is a traditional way of life in Botswana.

The controversial history of fence-building in Botswana is closely tied to the nation's beef industry. In 1972, when exports were becoming an important part of that industry, the European Union offered large subsidies to the beef exporters. There was just one condition on the exports: the beef had to be certified free of foot-and-mouth disease.

Some people argued that the disease can jump from wildlife to livestock—though to this day there is no conclusive proof that it does. Nevertheless, to meet the requirements of the E.U., the Botswana government decided to erect fences to segregate livestock from wildlife. Whatever its merits in disease control, fencing has clearly paid off in reassuring European beef buyers. Today, Botswana receives a tariff break of as much as 92 percent on beef exports to the European market.

But beef exporting and cattle farming are not the only keys to the Botswana economy. Botswana's new engine of growth is tourism, a wildlife-based industry. Tourism brings $240 million a year into the economy, accounting for almost 12 percent of GDP. It is also the country's fastest growing sector. And the interests of tourism are running smack into conflict with the interests of the beef industry.

At the heart of the conflict are the fences, which have turned Botswana into a jigsaw puzzle of isolated land fragments that neither cattle nor wildlife can navigate freely. And of all the fences that adversely affect wildlife, the ones proving most harmful are undoubtedly the fences that interfere with migrating species. One notorious incident in 1983 dwarfs the zebra debacles of 2004 and 2005. A severe drought in the Kalahari game reserve in central Botswana prompted a massive migration of wildebeest. The animals were following an ancient route to water when they were stopped by the Kuke fence on the eastern border of the reserve. Some 65,000 wildebeest piled up dead in heaps against the fence.

The conflict over fences presents a nasty dilemma for the government because Botswana has deliberately nurtured its lucrative tourism industry: it is known for its policy of low-impact tourism, favoring small tourist groups because they are less harmful to the country's delicate ecosystems. Yet in the past few decades hundreds of thousands of animals have died of thirst and exhaustion while trying to get around the seemingly endless fences. And the

continuing pastoralism of the tribes makes massive barriers such as the Makgadikgadi fence, the containment method of choice in Botswana. The Director of the Department of Wildlife and National Parks, which commissioned the Makgadikgadi fence, did not return repeated requests for comment.

In fact, the original call for the Makgadikgadi fence came not from the government or from the beef barons, but from local villagers. What triggered their demand was the drying up of the Boteti River. The Boteti was once a wide watercourse that took its life from the great Okavango River and gave life, in turn, to tall acacia and fig trees and to succulent grasses along its banks. The western edge of Makgadikgadi Park closely follows the channel of the Boteti, a boundary that made good sense when the Boteti was still an oasis. That way, when the animals in the salt pans of Makgadikgadi Park headed west in the dry season, their destination remained accessible. But in 1992 a brutal drought hit the region, and the Boteti, after waning to a chain of puddles, ceased flowing altogether. To this day, the riverbed remains dry.

When the Boteti dried up, a natural barrier also disappeared. The villagers' cattle could now cross the riverbed to graze in the park, and lions, hyenas, and wild dogs could sneak into the sandy village lands and feast on scrawny, slow-moving cows. The livestock losses brought the issue to its boiling point.

"I wish we could kill wildlife when it kills livestock, instead of getting little compensation from the government," said one cattle farmer. Another noted that the government's compensation for crop damage was less than the cost of transportation to pick it up. A third farmer pointed out that to the villagers, tourism brought no benefit.

The villagers brought their complaints to the *kgotlas*, Botswana's traditional community councils. Elders of the councils went to the legislature and, in 1995, proposed a single fence between the park and the villagers' lands. Botswana's department of wildlife then hired a consultant who proposed that the fence mostly follow the west bank of the Boteti where most of the predator attacks had taken place. The proposal also included gates in the fence, so that livestock could scrounge for the water now beneath the Boteti riverbed. But after further discussions between the department of wildlife and the local communities,

Herds of elephants and zebras gather around one of two water holes they can reach from the east side of the Makgadikgadi fence. The owner of one safari camp pumped water into this hole for the animals every day during the most recent dry season.

Makgadikgadi salt pans are transformed almost beyond recognition with the seasonal change from dry (left) to wet (right). The dry season lasts eight months, but when the rains come, the land turns lush, and the earlier barrenness of the landscape becomes easy to forget.

the fence evolved into a continuous cordon, made up of two parallel fences and a roadway in between. The fence on the wildlife side would be electrified; the cattle-side fence would not.

As government officials worked out the design of the fence, the farmers' conflict with the wildlife spiraled out of control. Cattle continued to be killed, and reports circulated that elephants were trampling farm equipment and destroying crops. In the ten months before the fence was completed, the department of wildlife received about 300 complaints from villagers. The villagers retaliated with snares, guns, and poisoned cow carcasses, ultimately killing twelve of the park's forty lions.

At the same time, the government was also trying to reassure people concerned about how the fence would affect migrating wildlife. In 1999 the department of wildlife took the unprecedented step of commissioning an environmental-impact study of a new fence in Makgadikgadi Park. The study emphasized that the park animals had to have access to water holes and that water would have to be pumped for them during the dry season. It also recommended that the fence have no jagged turns.

Yet despite more than $160,000 invested in the environmental study, the government disregarded all three of its recommendations. Only a handful of sources of pumped water were installed along the dry Boteti. The government also added a few loops and right angles to the fence at the last minute, according to Craig Gibson, an independent consultant at the Environmental Investigation Agency, an organization based in London that investigates environmental crime. The loops and angles became key factors in the zebra deaths. The wildlife became confused by the unpredictable alignment, Gibson explains—a confusion that often turned deadly. At other points, the fence was constructed so close to water holes that predators stampeded the zebras and wildebeest into the fence.

Why did the government ignore the report it commissioned? Early in 2000 the director of the department of wildlife, together with a group of village elders, took a helicopter ride over the Boteti to determine the path of the fence. They had previously agreed on a "give and take" design in which the fence would zigzag back and forth across the riverbed, as the report recommended. That way, some water holes would be on the villagers' side of the fence, and others on the park (wildlife) side.

But the elders convinced the government to alter the design, leaving the greatest part of the Boteti riverbed, with its underground water supply, outside the boundaries of the park, out of reach of the wildlife. Furthermore, the typical interaction between the government and the villagers ceded even more underground water to the villagers' livestock. A representative from the department of wildlife would arrive at a site to negotiate the exact location of the fence. A villager would then learn that some part of the riverbed near his land was to be on the park side of the fence. The villager would plead with the official: His ancestors were buried on that land. The land had been in his family for generations. His neighbors had unfairly gotten full riverbed access. And so, unarmed with GPS data and sympathetic to the villagers' concerns, the representative would give in.

In the end, tens of thousands of animals were left almost without water. Only two watering holes were available on their side of the fence during the dry season. David Dugmore, the safari-camp owner with a commercial interest in protecting wildlife, installed a pump himself in a water hole near his camp. "Even before the fence was up, I saw no effort being made to supply these animals with water near my camp, so I decided to do it myself," says Dugmore.

But like many others living near the fence, Dugmore has mixed feelings. "I don't like the idea of a fence," he says. But he does allow that it was tough without the fence for wildlife to compete with cattle in the grazing areas on the park side of the

riverbed. The conflict between the animals and the cattle farmers before the fence was built had also made things hard for Dugmore's business. "It was very difficult for me to show the wildlife to my guests," he says. "The animals became very nervous and would only come down to drink at night."

Villagers, too, are evenly divided about the fence. A. Clare Gupta, a specialist in environmental studies, policy and management, surveyed the villagers in 2004. She found roughly equal numbers of those who were happy about the fence—who said it brought benefits such as less predation on livestock—and those who saw no benefits from it. The happy ones said things like, "Before the fence, twenty cows, ten calves, and all my goats were killed. Now, only four cows have been killed." The dissatisfied villagers complained mainly that the fence had come at a high cost, mostly in lost grazing areas for their cattle. Some also said the fence was ineffective at keeping out predators or other wildlife that eat crops.

Gupta herself is troubled by the fence. In her view, the government's focus on a fence ruled out more long-term alternatives for resolving the conflict between wildlife conservation and the villagers' livelihood. "The fence was not the only nor the best solution to the problem," she says, "and the proof is that complaints are still coming from both sides."

Gupta thinks the government should instead have channeled its resources into developing a multiuse zone where villagers could participate in ecotourism campsites around the edges of the park. Local people must benefit directly from wildlife, she argues, if their attitudes toward it are to become more positive. But changing attitudes and integrating villagers into tourism run headlong into tribal culture. The safari is an alien concept to villagers who see the national park as grazing land and wildlife as a source of food and as a threat to their cattle.

According to environmental experts, the fence has achieved some limited success in separating wildlife from livestock. Chris J. Brooks, a wildlife biologist at the University of Bristol, England, notes that the cattle were outcompeting both zebras and wildebeest for grazing lands, forcing the wildebeest population in particular to travel long distances to graze. "By taking cattle out of the system," Brooks says, "you increase the available resources substantially. I think the fence is going to be beneficial in the long term."

At the same time, by building the fence, the Botswana government has placed itself in a difficult position. It must now mediate among various groups with seemingly irreconcilable differences. Yet according to the department of wildlife, the intensity of the conflict between villagers and wildlife, at least, is subsiding. Villager complaints about lions and elephants, for instance, have dwindled from hundreds per year to just a handful in the past two years. And the government is making a substantial effort to turn the fence from necessary evil into shared solution.

From this vantage point, at least, the strategy henceforth seems to be to give something to everyone, without forcing any side to give up ground it has already gained. For example, the government plans to extend the fence to the eastern border of the park. Yet while preparing to extend the fence, the government has also committed $250,000 to dig nine water holes at strategic sites in the park.

Sibangane Mosojane, the district wildlife coordinator of the department of wildlife, says the water

Plains zebras (Equus burchelli) search for water along the dried up Boteti River during the dry season. The Botswana government plans to dig nine water holes for the wildlife.

holes will be ready by the time the next dry season begins. The department of wildlife is also planning to collapse part of the fence during the dry season, and so allow animals to cross to water. But, careful not to antagonize the villagers, Mosojane says the fence would be opened for only an hour or two at a time—and never at night, when prowling lions might be able to slip through unnoticed.

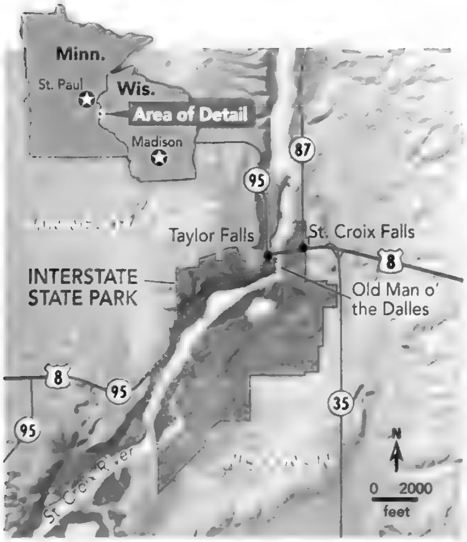
It is not clear, of course, how smoothly the new measures will run when the next dry season turns paradise into a desert of gleaming salt. What is clear, amidst all the uncertainty and contradictions, is that the fence is not going away. After putting $6.5 million into the fence, the government is not about to take it down. □

St. Croix River flows south into the distance, separating the western, Minnesota side of Interstate State Park (cliff in foreground) from Wisconsin, on the far side.

Along the Pothole Trails

A river that runs between Minnesota and Wisconsin has left a legacy of its wild youth.

By Robert H. Mohlenbrock



Potholes are saucer-shaped or cylindrical depressions scoured into hard rock surfaces by whirlpools of water carrying fine gravel. Such abrasive whirlpools can form in swift streams or in waters stirred by the wind; in either case the hollow you see today may be the result of thousands of years of weathering. On the east side of the St. Croix River, near St. Croix Falls, Wisconsin, there are dozens of potholes of various size and shape, including what is billed as "the world's most perfect pothole": a circular hole about four and a half feet wide and eighteen feet deep, with spiral striations on the inside surface of its walls. On the western, Minnesota side of the river are numerous other potholes, many of irregular shape and some as deep as sixty-seven feet. All of the depressions are known as glacial potholes because they were carved by rushing glacial meltwater. The potholes, along with scenic gorges, fanciful rock formations, moist and dry woods, and other natural attractions, are protected within the boundaries of Interstate State Park, which spans the St. Croix River and parts of both states.

Before the potholes could be sculpted, the rock had to be in place. The oldest rocks exposed here are volcanic, part of an accumulation of lava that flowed from deep within the earth into what is now the basin of Lake Superior. The lava flows, which began about 1.1 billion years ago, are 14,000 feet thick at Interstate State Park. (Closer to Lake Superior, 1,000 miles away, they are 60,000 feet thick.) Following the formation of the lava rock, great seas flooded the region several times, leaving deposits of gravel and sand. The deposits consolidated into sandstone, shale, and conglomerate rock. The seas subsided about 70 million years ago, and rivers began to cut into the layers of rock.

About 1.8 million years ago the climate cooled, snow fell faster than it could melt, and continental glaciers began to form. Four times glaciers ground southward across the site of what is now Interstate State Park, before they melted and retreated, leaving gravel, stones, and other debris behind. Then, about 10,000 years ago, as the last ice age was ending, glacial Lake Duluth began to fill. The lake—the precursor of Lake Superior—spawned the St. Croix River, whose raging waters began to break through cracks in the lava rock. The river and its branches eventually carved canyons that can be seen in Interstate State Park. Waterborne sand and gravel, swirling in whirlpools, gradually carved out the glacial potholes. As the rivers dug deeper, narrower

channels, the potholes were left exposed at their margins.

Although the potholes were shaped mostly by sand and gravel, boulders, too, were whirled around inside the potholes, and the boulders' edges were gradually rounded off. Today those boulders are shaped like cannonballs, some as large as four feet in diameter. Visitors to the Ice Age Interpretive Center can stand in awe of several of them, stationed outside the front doors of the center, on the Wisconsin side of the park. The Pothole Trail, also on the Wisconsin side, shows off several glacial potholes, including the "perfect" one, as well as spectacular views of the St. Croix River gorge and a cliff formation known as the Old Man o' the Dalles (dalles—the word rhymes with "pals"—are rapids in a river confined between steep canyon walls).

Sulphur fungus (Polyporus sulphureus)

Another Pothole Trail, on the Minnesota side of the river, gives visitors a tour of some large glacial potholes. One of them is twelve feet across the top and sixty-seven feet deep; another is nearly forty feet across and about forty feet deep. A small flowering plant known as waterwort grows in several of the potholes that contain standing water.

ROBERT H. MOHLENBROCK is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.

Rock climber tackles a pothole wall.

VISITOR INFORMATION
Interstate State Park
P.O. Box 703
St. Croix Falls, WI 54024
715-483-3747
dnr.wi.gov/org/land/parks/specific/interstate

Interstate State Park
P.O. Box 254
Taylor Falls, MN 55084
651-465-5711
www.dnr.state.mn.us/state_parks/interstate

Habitats

Bluff top The dry bluff tops are home to plants and short trees that can survive on limited moisture. The most common tree is bur oak; others include eastern red cedar, hop hornbeam, jack pine, white ash, and white oak. Creeping juniper, a sprawling shrub, is nestled among large boulders; eastern prickly pear grows in the open among the rocks. Poverty oat grass, with curly leaves at the base and slender flowering spikes, thrives in the dry, rocky soil. Common polypody and rusty cliff fern, two low-growing ferns, live in rock crevices.

Wildflowers include Canada columbine, common yarrow, divaricate sunflower, golden corydalis, harebell, Pennsylvania sedge, pennyroyal, prairie alumroot, shining bedstraw, spreading dogbane, starry false Solomon's seal, and tall corydalis. Sand fameflower, a summer-blooming succulent, opens its blossoms each day for only an hour, at about two o'clock in the afternoon.

Moist woods The ravines harbor moist woods dominated by basswood, bitternut hickory, hop hornbeam, paper birch, sugar maple, white ash, and white oak. The shrub layer is sparse, though snowberry is fairly common. Most of the wildflowers in the understory are spring bloomers; they include bland sweet cicely, Canada anemone, common blue violet, common enchanter's nightshade, eastern waterleaf, false Solomon's seal, red baneberry, Solomon's seal, white avens, wild geranium, and wild ginger.

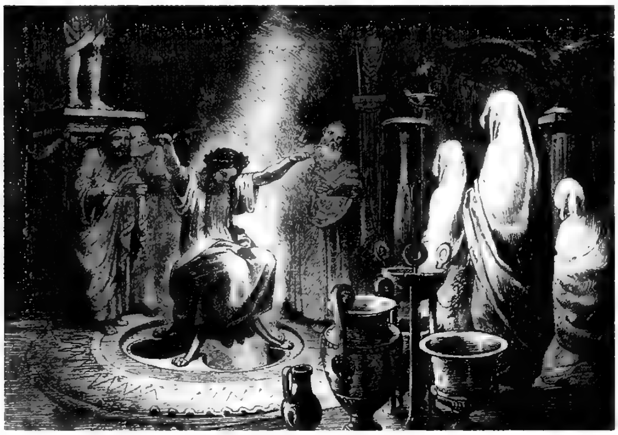
Upland woods On the upper slopes of the ravines are relatively dry woodlands dominated by northern red oak, slippery elm, white ash, and wild black cherry. The wildflowers of this habitat bloom mostly in summer and fall; they include American figwort, forest lousewort, lopseed, old-field five-fingers, tall white beardtongue, wild bergamot, and zigzag goldenrod. Crested wood fern, rattlesnake fern, and toothed wood fern are scattered throughout the woods.

Seeps Water seeps from fissures in many of the cliffs, often draining into depressions where boglike conditions prevail. These low areas are often covered by masses of mosses, including sphagnum. Numerous species of sedge also grow here, some forming mounds. Among the other plants are boneset, jewelweed, marsh fern, marsh marigold, northern blue flag, sensitive fern, skunk cabbage, swamp saxifrage, water scorpion grass, and white turtlehead.

By Laurence A. Marschall

The Oracle: The Lost Secrets and Hidden Message of Ancient Delphi
by William J. Broad
Penguin Press, 2006; $25.95

Long before focus groups and computer modeling came into vogue, a woman (actually a succession of women) known as the Oracle of Delphi was the arbiter of choice for politicians and military planners in ancient Greece. No carnival fortune-teller, she was consulted on important matters of state, from questions of inheritance and taxation to issues of crime, government and war. The Delphic Oracle and her prophecies were extensively documented in classical texts, and so modern scholars have a pretty good idea of who she was and how she did her work.



Seeress of Delphi inhales the gas, or pneuma, that entrances her (nineteenth-century image).

For nine months of the year, from March through November, the Pythias, a priestess of Apollo, conducted audiences in the temple of the god in Delphi. Seated on a three-legged stool in a holy chamber, she entertained the questions of petitioners. Then, after taking a few breaths of a sweet-smelling gas, or *pneuma,* which rose from a fissure below her, she would pronounce, normally in verse.

Her words were sage, suggestive, and invariably effective. "Love of money and nothing else will ruin Sparta," she warned, setting the agenda for a Spartan policy of militarism, physical fitness, and frugality. "Sit in the middle of the ship, guiding straight the helmsman's task," she warned Solon, the Athenian lawgiver, directing him toward a policy of moderation and compromise that served his city well.

Yet as Greece declined and the centuries passed, the temple, shrines, and statues of Delphi fell into disrepair—desecrated by Christian zealots, ransacked by armies, tumbled by earthquakes, buried by landslides. By the late nineteenth century, stories of the Oracle had taken on the flavor of legend. Then, in 1892, archaeologists unearthed the remains of Apollo's temple on the hillsides of Mount Parnassus, under the small village of Kastri. As the dig progressed, most of the ancient descriptions were verified: the temple and its inner chamber slowly emerged. Archaeologists even found a marble slab on which the Oracle's seat may have rested, and a rounded stone, called the *omphalos* ("navel"), which represented Delphi's place at the center of the world. What was missing, however, was the cleft that emitted *pneuma,* the mysterious substance that made the seeress see. That part of the story, in the conventional wisdom of the time, must have been malarkey.

William J. Broad, a Pulitzer-Prize-winning science writer for *The New York Times,* picks up the strands of Oracle history with the story of the missing cleft. His tale focuses on the work of several scientists, notably Jelle Zeilinga de Boer, a geologist at Wesleyan University in Middletown, Connecticut, and John R. Hale, an archaeologist at the University of Louisville in Kentucky, who, against the weight of scholarly opinion, set out to show that a strange gas was indeed seeping into the Oracle's holy of holies.

Sure enough, de Boer identified geologic faults running through the basement of the temple that could readily have channeled petrochemical gas during the years the Oracle was holding forth. What is more, an analysis of ancient gases trapped in porous rocks at the Delphic spring, along with samples of the water that flows there now, showed that among the gases the Oracle might have breathed was the sweet-smelling and intoxicating gas ethylene. De Boer and Hale even enlisted a toxicologist named Henry A. Spiller to administer low doses of ethylene to several human subjects, to determine whether it might induce the trancelike behavior attributed to the Oracle. It did.

So is that all there is? Was the great Oracle "as much glue sniffer as guru," as one journal has put it? Broad, usually a hard-nosed reporter, thinks not. In the penultimate chapter, he suggests that ethylene just might be a gateway to a world beyond scientific reductionism.

Or maybe not. Like so much of what scholars and supplicants have learned from the Oracle in the past, the answer is open to interpretation.

Voyage of the Turtle: In Pursuit of the Earth's Last Dinosaur
by Carl Safina
Henry Holt and Company, 2006; $27.50

The leatherback turtle, the heaviest of all wild reptiles, is a nautical jet-setter, a natural-born citizen of the world. After rounds of breeding on Trinidad's Caribbean coast, a leatherback gourmand may head for Grand Banks, thousands of miles to the north, where abundant raw jellyfish can be found. When the party crowd gets dull in Japan, a leatherback lothario may cross the Pacific Ocean to Baja California, where leatherback females, instinct tells him, are really going wild. Powerful swimmers and uncanny navigators, these giant sea turtles are ever in motion, girdling the globe with ease.

The central voyage in Carl Safina's narrative, however, is the author's own.

The stops along the way are the many strands and seascapes frequented by these marvelous creatures. He watches female leviathans scrabbling ashore to

Leatherback hatchling embarks on the first swim of its globe-trotting life.

nest on the beaches of the Caribbean, observes mother turtles laying clutches of eggs in the shadows of condos in Florida and South Carolina, counts nests from the air on beaches along Mexico's Pacific coast, and traces turtle tracks along the almost deserted northwest coast of Papua New Guinea. Wherever he goes, he chats with fishermen, scientists, and conservationists who know the great reptiles intimately.

Although the media give more air time to whales than to turtles, a remarkable amount of effort has gone into understanding sea-turtle behavior, and even more into protecting them from acute threats to their survival. Their main enemies these days are poachers who steal their eggs; shoreline development, which disturbs their nesting grounds; and industrial fishing, which snags them in nets and on fishing lines.

A sense of wonder suffuses Safina's luminous prose. It is impossible not to marvel along with him at the great turtles' seagoing prowess. Turtles can dive deeper than whales—the deepest known leatherback dive is 3,900 feet—and can stay under water for more than an hour on a single gulp of air. Loggerheads and green turtles, cousins of the leatherback, can hibernate under cold

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water for weeks. Leatherbacks also generate their own heat, keeping as much as 40 Fahrenheit degrees warmer than their surroundings.

A sea turtle's senses, at least out of the water, can sometimes seem out of kilter—hatchlings, heading out to sea at night, often confuse the lights of condos and parking lots with the bright horizon of open water. Yet once at sea, the turtle is as flawless a navigator as an airplane equipped with GPS. Leatherbacks fitted with satellite transmitters have been tracked back and forth across the Atlantic and the Pacific, and females have returned, after an absence of more than a decade, to the stretch of beach where they were born.

Like so many natural-history narratives these days, Safina's is tinged with anxiety. In some areas, particularly in the Pacific, leatherback populations have plummeted, ravaged by development ashore and by unregulated fishing at sea. Yet in the Atlantic, where many shoreline communities have seasonal regulations on lighting to accommodate nesting turtles, and where U.S. commercial shrimping nets are now equipped with turtle escape devices, leatherbacks seem to be flourishing. Some populations are even growing back exponentially. Sea turtles have been around for a hundred million years or so, and with a little help from people like the ones in Safina's book, they may swim the seas for hundreds of millions more.

Sky in a Bottle
by Peter Pesic
MIT Press, 2006; $24.95

Why is the sky blue? That innocent question is the point of departure for Peter Pesic's magisterial history of light in the atmosphere. Its form recalls the encyclopedic monographs of a century ago, focused on a single point of erudition and replete with footnotes in exotic tongues and arcane alphabets. Pesic is a tutor and musician-in-residence at the campus of St. John's College in Santa Fe, New Mexico, whose curriculum emphasizes the study of great books of the Western tradition. So the mode of discourse the author has chosen suits him just fine.

But fortunately for the reader, the scholarly Pesic has eschewed obfuscation and produced a succinct and approachable intellectual history that sheds light on the entire scientific enterprise. *Sky in a Bottle* begins, not surprisingly, with the Greeks, who debated all the fundamental elements of the blue-sky problem: the structure of the heavens, the phenomenon of color, and the nature of vision itself. Does the eye send out a stream of fire that "feels" the objects it senses? Or do luminous objects give off rays of some kind, which convey color to the viewer?

Fanny Brennan, Sea Mail, *1987*

It was not until the late nineteenth century that those questions were fully resolved, and with them the question about the color of the daytime sky. Light, as it is understood today, is a form of electromagnetic wave produced by the vibration of atoms. The wavelength of light largely determines the color we perceive. Sunlight, which illuminates the sky, has a wide spectrum of wavelengths, but molecules of air preferentially scatter the short, blue wavelengths. By the same token, the longer wavelengths—green, yellow, red—tend to pass straight through the air, so the color of the Sun we see is an aggregate of those colors. So when we look at the air instead of the Sun, we see the scattered, blue light—the color of the sky.

Virtually every major philosopher and experimentalist in Western science contributed to this understanding. They include household names such as Newton—who pioneered the study of the spectrum—as well as physicists revered only by their own: Augustin-Jean Fresnel, Christiaan Huygens, James Clerk Maxwell, and Thomas Young. Leonardo da Vinci, the Renaissance polymath and artist, thought deeply about how the atmosphere affected colors. Indeed, Leonardo gets the credit for the invention of "aerial perspective," whereby the artist can make the features in a landscape look distant by adding some subtle bluish tints. Leonardo's notebooks also document an experiment to re-create the azure of the sky in a bottle by shining light through water-filled containers.

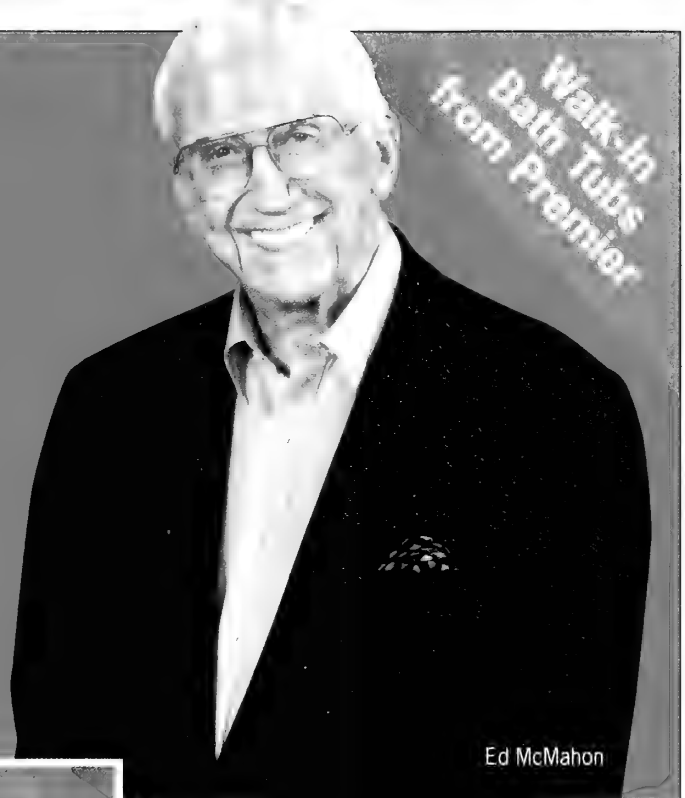
Lesser known, but equally inventive, was Horace-Bénédict de Saussure, an eighteenth-century Swiss naturalist whose passion was mountain climbing. To measure the blue of the sky, which seemed to darken the higher he went, de Saussure developed a "cyanometer." Then he discovered that a solution of copper sulfate and ammonia could reproduce a jar of heaven even more convincingly blue than Leonardo's bottled sky.

References to the blue of the sky occur throughout Western art and literature, and Pesic quotes from a wide range of artists and writers—the abstract painter Wassily Kandinsky, the novelist Gustave Flaubert, the poet Wallace Stevens, even Edgar Allan Poe—on the baffling color of the heavens.

Some may fault Pesic for casting his net too widely, for mixing science, philosophy, literature, and art with little discrimination. Yet this little gem of a book succeeds on a premise that echoes the early debates of the Greeks about the nature of light: that nature is more than just physical forces acting on passive receivers. The blue of the sky owes as much to mind as to matter. Pesic puts it succinctly: "The sky as we see it always remains in the ultimate bottle: the human brain."

LAURENCE A. MARSCHALL, author of The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

"A relaxing bath is something we all have a right to."



Ed McMahon

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(Continued from page 12)
Christine Mlot's article ["Alaska's Underground Frontier," 4/06] is a fitting tribute to those often unsung heroes. The Microbial Observatories program, funded by the U.S. National Science Foundation, is an important starting point, but lists of taxa and the discovery of new diversity are less important than increasing the understanding of how microorganisms interact with one another and their environment as they grow, reproduce, and survive in soil. Microbial responses to environmental change may be particularly critical. In northern latitudes, for instance, the fungal response to climate warming may determine to what extent permafrost soils will release carbon dioxide into the atmosphere, creating a positive feedback to greenhouse warming.
Teri C. Balser
University of Wisconsin–Madison

Minnie Diva

Not all mice sing in an ultrasonic voice ["Samplings: Melodious Mice," 2/06]. In 1932, when I was about fifteen, my parents, my four siblings, and I saw a mouse that sang like a canary. When we first heard it, it was inside a wall space about six inches wide, between the living room and the kitchen, and we were puzzled about how a canary had gotten into the space. Almost every night for a few weeks we heard the song. One night the song sounded much louder. There in the doorway between the living room and the kitchen was a mouse, sitting on its haunches, singing its canarylike song. We heard it many times thereafter, but we never saw it again.
Harrison C. Mondy
Pasadena, California

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

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Ben's 300th

By Robert Anderson

Years ago, when I was walking through the Paris neighborhood of St.-Germain-des-Prés, a bronze plaque caught my attention. More precisely, it was the name that caught my eye: Benjamin Franklin. On September 3, 1783, the plaque noted, at 56 Rue Jacob, Franklin, John Jay, and John Adams signed the Treaty of Paris, George III's formal recognition of the colonies' independence.

Only now, however, as I check out the Web sites that mark the 300th anniversary of Franklin's birth, have I come to fully appreciate how he reached that triumphant moment. Although Franklin was a well-spoken gentleman and a successful businessman, his fame as a scientist was his entrée to European society. It gave him the clout to secure the French aid so critical to keeping the War of Independence afloat. Thus his experiments with electricity led, albeit indirectly, to the birth of the United States.

Not surprisingly, Franklin, one of the most widely recognized Americans of his age, has a huge Web presence. Start with the tercentennial site (benfranklin300.com), created by a consortium of Philadelphia-based institutions. The section titled "Useful Knowledge" delves into his scientific accomplishments. Back on the main menu bar, click "Et Cetera" and you'll find a link to the best list of annotated Franklin links on the Internet.

Franklin continued to dabble in science while representing Pennsylvania in London from 1757 until 1775. The Franklin Institute, a Philadelphia science museum famous for hands-on learning, has a self-guided tour of Franklin's contributions (fi.edu/franklin/tour). At the American Philosophical Society (our nation's oldest science institution, founded by Franklin in 1743), a special exhibit focuses on Franklin's little-known relationship with a Russian princess named Ekaterina Dashkova forged to promote the exchange of scientific knowledge (www.amphilsoc.org/exhibitions/princess.html).

Myths still surround many of Franklin's achievements, some needlessly embellishing his work. For example, some people still credit him with discovering the Gulf Stream, when in fact he only charted it with temperature measurements during his many Atlantic crossings. At oceansonline.com/ben_franklin.htm you'll get the full story.

At ushistory.org/franklin click on "The Kite Experiment" for a rundown on his work on electricity. The Public Broadcasting Corporation has an interactive version of Franklin's most famous experiment, where you can fly a virtual kite yourself using diverse materials in a variety of weather conditions. (From www.pbs.org/benfranklin click on "Explore" and then on the unit "How Shocking.") Contrary to popular belief, lightning was not involved in Franklin's experiment. He knew enough to avoid it.

My favorite Franklin site, however, was created by one Robert A. Morse while a fellow at the Wright Center for Science Education at Tufts University (tufts.edu/as/wright_center/fellows/bob_morse_04/). In nine lessons titled "Ben Franklin As My Lab Partner," Morse explains how to reproduce Franklin's electrostatic experiments. The lessons are accompanied by thirteen video clips that show how to build the apparatus with ordinary items such as aluminum foil, Christmas tinsel, pencils, and Styrofoam cups. If all the grade school science teachers across the country exposed their students to the fun of these lessons, Franklin's scientific contributions might gain the broad appreciation they deserve. I can't think of a better way to celebrate Ben's 300th birthday than generating a few sparks.

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

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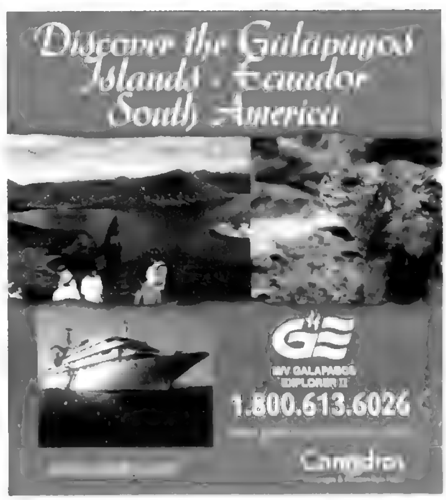
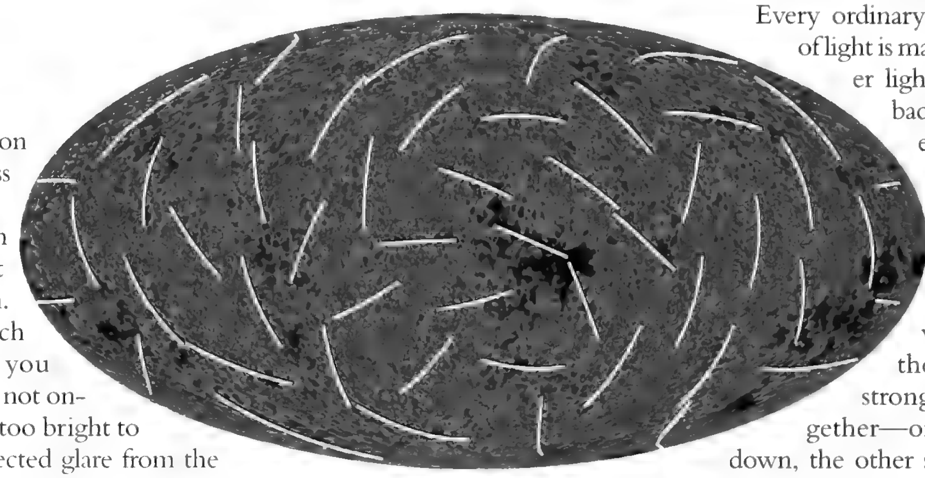


OUT THERE

Shades of the Past

A clearer view of cosmic inflation, through the polarized light of the big bang

By Charles Liu



Full-sky map, rendered in false colors, shows the temperature distribution of the cosmic microwave background (CMB), as measured by NASA's Wilkinson Microwave Anisotropy Probe. Relatively cold regions are shown in blue, relatively warm regions in red. Along the white bars are regions in which the orientation of the polarization of the CMB radiation field remains the same. Although imperceptible to the eye, the correlation between temperature "hot spots" and polarization strengths provides the best observational evidence to date in support of the inflationary model of the universe.

It's late afternoon on a cloudless day at the beach, and the Sun is hanging just above the horizon. You want to watch the sunset, but you can't bear to look: not only is the Sun itself too bright to view, but the reflected glare from the waves hurts your eyes. No problem: you slip on a pair of polarized shades, and voilà! You still can't look directly at the Sun, but the glare off the ocean is gone.

Polarization is one of those scientific terms that show up in regular speech all the time. Unfortunately, the political sense of the word is almost the reverse of its optical sense. A polarized citizenry, of course, is one whose opinions are so divided that the camps might as well be coming from opposite poles of the world. Polarized light, by contrast, marches in lock-step; it's uniform and coherent.

Polarized light comes at us through polarizing sunglasses and camera filters, as well as from such technogadgets as cell-phone screens, computer monitors, and flat-screen TVs. It also emanates from almost any reflective surface—the ocean, for instance.

You can add the universe itself to your list of polarized-light sources. In fact, polarized light has long been a vital tool for us astronomers. Much of what we know about dust-enshrouded, supermassive black holes in distant galaxies, for instance, comes to Earth because of polarized light. Now, thanks to astronomers working with the Wilkinson Microwave Anisotropy Probe (WMAP)—a satellite that has been orbiting some 900,000 miles above the Earth since June 2001—polarization has been detected and measured in the oldest light of the cosmos: the afterglow of the biggest bang of all.

Light travels from place to place in waves. In an ocean wave, the water just goes up and down as the wave passes by, but the energy moves along the wave until it crashes on the shore. A light wave works the same way: picture a rope wiggling up and down really fast, and you'll get the idea. But unlike waves on the ocean, light isn't restricted to up-and-down waves; waves in a beam of light can go up and down, side to side, or any diagonal tilt in between—all as they come toward you. The result is a complex, braidlike beam—like a whole bunch of wiggling ropes, intricately interwoven but not interfering with one another, carrying energy forward along their gyrating lengths.

Every ordinary (unpolarized) beam of light is made up of lots of weaker light waves, all wiggling back and forth at different tilts. Each wave can be broken down into up-and-down and side-to-side components; so when you add up all those weaker waves, you get the equivalent of two stronger waves added together—one wiggling up and down, the other side to side. In ordinary circumstances, light is likely to move forward completely randomly, so the up-down and side-to-side waves are equally strong. But if some physical process makes one wiggle direction of light stronger than the other, the light becomes polarized [*see illustration on page 66*].

So, if you build a filter with long, thin, parallel strips, it'll let through only the light wiggling in one direction (say, up and down), while blocking the light that wiggles in the other direction (say, side to side). The light that comes through the filter is polarized—more orderly and less bright. You can imprint such a filter onto a piece of plastic, and presto! glare-reducing sunglasses! Or you can sandwich some gelatinous filter material between sheets of glass, and control the amount of polarization with weak electrical signals. Wow! Flat-screen TVs!

Out there, polarization happens naturally where light gets reflected or scattered a lot. For example, a few paragraphs earlier I mentioned supermassive black holes. Such a black hole

(Continued on page 66)

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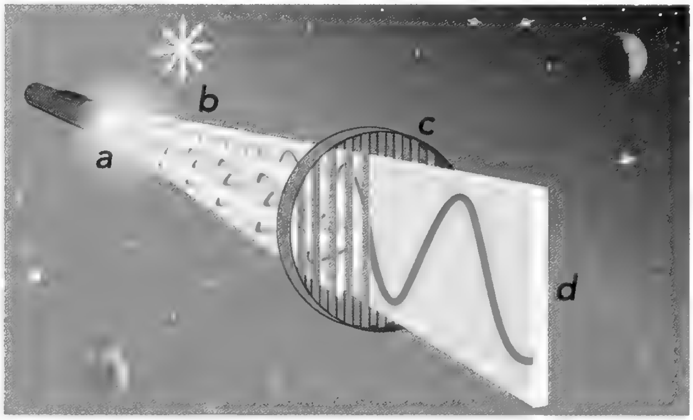
 (Continued from page 62)

is straddled by a doughnut-shaped cloud of dense, hot gas. If we here on Earth see it side-on, the doughnut "hole" points at right angles to our line of sight; all we see is the obscuring gas, and we can't see down toward the black hole itself. But if light coming out of the doughnut hole shines into clouds of dusty gas farther away, some of that light will bounce our way off the dust in those clouds—the same way that smoke or fog in a flashlight beam reflects the light sideways into view. That reflected light is polarized, so by putting a polarizing filter in our telescope camera, we astronomers can isolate the light bouncing off those clouds—in effect, using them as giant angled mirrors to look into the doughnut and indirectly study the black hole within.

What about light that permeates the cosmos as a whole? The universe has been expanding at a more or less constant rate for billions of years. According to current theory, though, it swelled by the staggering factor of at least ten trillion trillion in size between 10^{-35} and 10^{-32} second after the big bang. To distinguish it from ordinary expansion, that expansion-on-steroids is called the inflationary epoch, or just inflation. Inflation is strongly supported by circumstantial evidence, but until now it had not been confirmed by any observational data.

For decades, though, astronomers predicted that inflation might have left a telltale imprint in the energy distribution of the early universe. That energy, observable today as the leftover heat from those early times, is called the cosmic microwave background (CMB)—the oldest direct signature of the big bang [*see "Sharper Focus," by Charles Liu, May 2003*]. Depending on how inflation actually happened, the amount of polarization in the background light would vary according to fluctuations in that light at any given location in space.

Here's how it all went down. Before inflation happened, the big bang sent powerful gravitational shockwaves through the infant universe. By then, the energy that filled space was already mottled with barely perceptible quantum fluctuations—the seeds of today's large-scale cosmic structure. So the interplay between the gravitational waves and the quantum fluctuations (within the first trillionth of a trillionth of a trillionth of a second after the big bang!) gave rise to patterns of electric and magnetic fields that in turn partly polarized the cosmic background light.



Polarization of light is depicted in the schematic diagram. An ordinary light beam (a) is made up of many waves that oscillate in any random plane that makes a right angle to the beam direction (b). A polarizing filter (c) passes only those wave components that oscillate in the same orientation as the filter. The resultant beam is polarized (d).

If, at this point, inflation kicked in, a whopping amount of energy flooded the universe, seemingly out of nowhere; then the energy flow must have shut off by the time the observed, normal rate of expansion resumed. In the basic inflation model, that shut-off would happen naturally if the broader, wider quantum fluctuations had bigger temperature variations than the smaller ones. Since the energy of inflation would have interacted with all of the still-traveling gravity waves and all of the still-present quantum fluctuations, that temperature-varying signature would have left a strong imprint in the polarization pattern of the cosmic background—many times greater than what had existed before inflation began.

The measurement—discerning the overall polarization pattern, and then isolating its various components—is brutally difficult. The structure of the CMB is subtle enough as it is, varying in temperature by less than one part in 10,000 across the entire sky. The variation in background polarization, in turn, is only a tenth to a hundredth the strength of those temperature variations. Amazingly, though, the WMAP team made the measurement.

By combining more than three years of data, the team measured the background temperature of the universe to a precision of several millionths of a degree, on angular distance scales varying from less than the width of the Moon to the breadth of the entire sky. Then they extracted the variation in polarization from that background temperature, and measured how much the polarization varies from one scale to another. The results appear to confirm two things: Larger-size fluctuations do seem to have greater temperature variations than smaller-size ones. And the temperature variations in the polarized light caused by gravity waves from the big bang are less than a third the strength of the variations unrelated to those waves. Both results suggest—for the first time with some observational confidence—that inflation did indeed take place.

That is a lot to wrap your head around, but then, the origin of the universe should be a little deep, right? And remember, it is all being studied through polarizing filters. So the next time you're at the beach, enjoying a sunset that is particularly sublime, you may experience a momentary oneness with the world. And maybe, as you reflect that the light passing through your glare-reducing shades is polarized, just like the oldest light in the cosmos, that sense of oneness will extend to the universe as well.

CHARLES LIU is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

THE SKY IN JUNE

By Joe Rao

Mercury puts on a fine show for much of June, not setting for as long as an hour and forty-five minutes after sundown. Look for it low above the west-northwestern horizon as twilight darkens. Mercury begins June at magnitude –0.9 but fades considerably thereafter. Although it gains its greatest elongation (twenty-five degrees east of the Sun) on June 20th, it reaches its highest altitude (eighteen degrees above the horizon at sunset) in the week before then, as seen from forty degrees north latitude. Around the 9th, the planet may be easy to confuse with two bright stars, Capella, far to its right, and Procyon, far to its left. On the 27th, Mercury appears almost exactly in line with the "twin stars," Castor and Pollux, in the constellation Gemini, the twins. A line from Castor through Pollux, extending a bit more than twice the distance between them, brings you to Mercury. Hovering about six degrees above the planet is a young crescent Moon.

Venus rises in the east with the first light of dawn, flaming at magnitude –3.8, a dazzling but low "morning star" you can pick out of the brightening daylight as sunrise approaches. On the 22nd binoculars should reveal the Pleiades star cluster six degrees to the north (upper left) of Venus. The following morning, an old crescent Moon, just two and a half days before new, is positioned well to the left of Venus.

In early June Mars sets about three hours after the Sun. Compared to its brilliant apparition last fall, the Red Planet now appears small and faint. During June it dims slightly, from magnitude 1.7 to 1.8, and it is now classified as a second-magnitude object. Not only is Mars on the far side of its orbit from Earth, but on the 26th it's also at aphelion, its greatest distance from the Sun.

Mars moves eastward throughout June, appearing within the Beehive cluster (aka M44) in the constellation Cancer, the crab, on the 15th. Mars is also approaching Saturn during the first half of June, and on the evening of the 17th, the Red Planet slides just 0.6 degree to Saturn's north (upper right). On the 28th Mars lies less than two degrees below a slender crescent Moon.

Jupiter is installed grandly in the south, a wonderfully easy target at dusk. Although Venus outshines it, Jupiter is the dominant light in its part of the sky and still offers a generously big disk for telescopes. The banded giant forms the base of a large isosceles triangle with the bright star Spica, in the constellation Virgo, the virgin; the brilliant star Arcturus, in the constellation Boötes, the herdsman, forms the apex of the triangle. On the evening of the 6th a gibbous Moon appears a few degrees west (to the right) of Spica; on the evening of the 7th it is situated below and to the right of Jupiter; and on the 8th, below and to the left of Jupiter.

Saturn is in Cancer in the western sky at dusk. On the 1st it sets about four hours after the Sun, but by the 30th it's setting around the time that the two-hour twilight is ending. Mars, moving much faster than the ringed planet, races up to meet Saturn by the evening of the 17th (see the description in the notes on Mars, above). In spite of its vastly greater distance from Earth, Saturn glows more than three and a half times brighter than Mars. The crescent Moon slides through this part of the sky on the evenings of the 27th and 28th. At mid-month Saturn's rings are tilted eighteen and a half degrees to our line of sight.

The Moon waxes to first quarter on the 3rd at 7:06 P.M., and to full on the 11th at 2:03 P.M. It wanes to last quarter on the 18th at 10:08 A.M., and becomes new on the 25th at 12:05 P.M.

The solstice takes place on the 21st at 8:26 A.M. Summer officially begins in the Northern Hemisphere; winter in the Southern Hemisphere.

Unless otherwise noted, all times are given in eastern daylight time.

Lizards & Snakes: Alive!

Opens Saturday, July 1

Snakes and their slithering and scurrying friends have always had, well, an image problem. But *Lizards & Snakes: Alive!* an engaging, family-friendly exhibition opening July 1, sheds new light on these magnificent, much-maligned creatures—lizards and their legless cousins, the snakes.

Veiled chameleon

Some 60 live examples of this group, known as a whole as squamates, will be on view, up close and personal, in meticulously re-created habitats with natural features from rock ledges to plants to ponds—whatever makes the animal feel at home, whether that's the Amazon, the Caribbean, or the Galápagos Islands. Specimens range from a four-inch tropical girdled lizard to a fifteen-foot Burmese python and also include geckos, chameleons, iguanas, boa constrictors, cobras, and more; in all, representing 27 distinct species.

Grounded in the group's evolutionary history, the exhibition explores how squamates developed so many shapes and sizes, came to live in so many habitats—all but the coldest and highest places on Earth—and acquired such remarkable adaptations as projectile tongues, deadly venom, clever camouflage, and sometimes surprising modes of locomotion.

"This exhibition dispels many mistaken notions," said Darrel Frost, Curator-in-Charge in the Museum's Department of Herpetology and Associate Dean of Science. "For instance, snakes are not slimy and are just an amazingly successful group of lizards that have lost their legs." He added, "This exhibition will leave the visitor with a sense of wonder at the remarkable diversity of this very large but underappreciated group."

The exhibition also conveys the latest research, reflecting ongoing work conducted by Museum scientists and their colleagues around the world, from boa- and pit viper–inspired innovations in remote sensing to advances in diabetes research made possible by the study of Gila monster venom.

Numerous interactive stations throughout invite visitors to listen to recorded sounds, zoom in on live geckos, follow a rattlesnake on the hunt, and view videos of lizards and snakes in action. "Squamates vary enormously in how they spend their lives," said Dr. Frost. "For example, how they hunt and capture prey, from using sticky projectile tongues as long as their bodies to swallowing prey much larger than their heads—the equivalent of a human swallowing a watermelon, with no hands!"

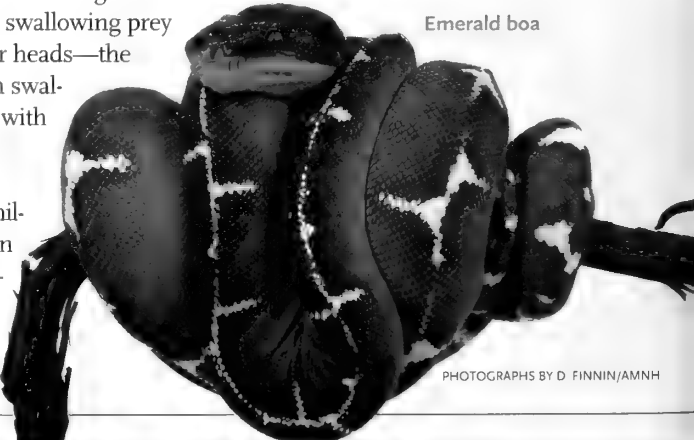
An activity center for children features more than a dozen hands-on activities, including skeletons to assemble, touchable skin casts, puzzles, and games. Among the highlights is a fossil cast of *Magalania prisca,* the largest-known terrestrial squamate, which lived in Australia from 1.6 million to 40,000 years ago and grew to 30 feet long.

Green tree monitor

The exhibition is curated by Dr. Frost, David Kizirian, Curatorial Associate in the Department of Herpetology, and Jack Conrad, Postdoctoral Fellow, Division of Paleontology.

Lizards & Snakes: Alive! is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with the Fernbank Museum of Natural History, Atlanta, and the San Diego Natural History Museum, with appreciation to Clyde Peeling's Reptiland.

Lizards & Snakes: Alive! is made possible, in part, by a grant from The Dyson Foundation and the Amy and Larry Robbins Foundation.

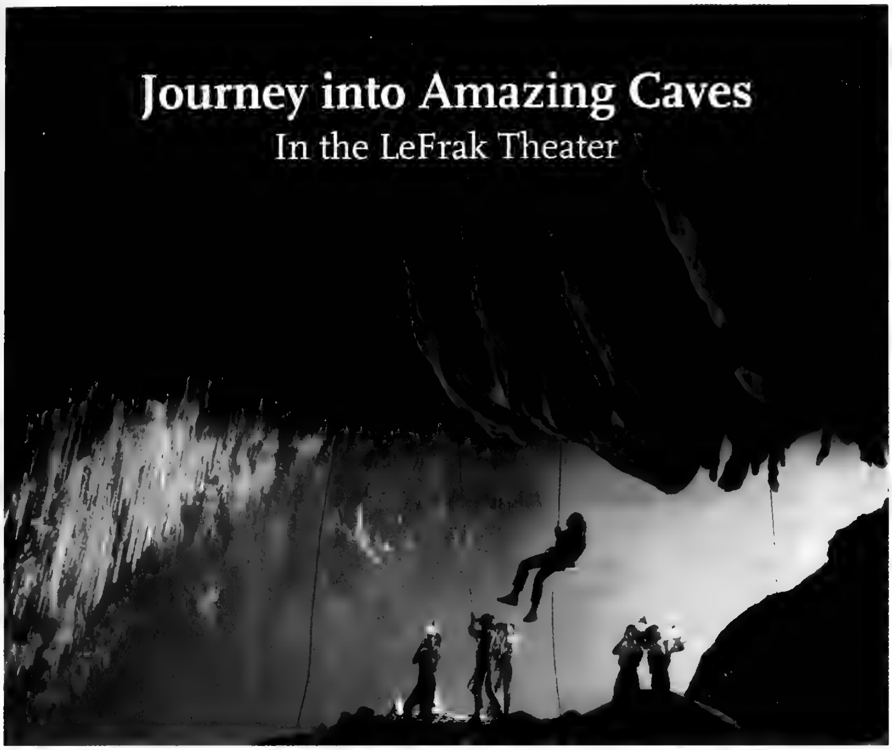


Emerald boa

PHOTOGRAPHS BY D. FINNIN/AMNH

Journey into Amazing Caves

In the LeFrak Theater



© MACGILLIVRAY FREEMAN FILMS

An underground cave where fragile speleothems have formed

Journey into Amazing Caves, a gripping IMAX film, follows cave explorer Nancy Aulenbach and microbiologist Hazel Barton as they search some of Earth's most extreme environments for micro-organisms with possible new medical applications. Narrated by Academy Award nominee Liam Neeson, the film is an adventure through natural underground landscapes that are as stunning as any place on Earth's surface. Audiences rappel down a sheer vertical cliff in Little Colorado River Canyon, Arizona; drop into shimmering labyrinths of ice in Greenland; and squeeze through the narrow, twisting, flooded passages of Dos Ojos in the Yucatán jungle, an underwater cave stretching over 38 miles.

IMAX films at the American Museum of Natural History are made possible by Con Edison.

Last Chance for *The Butterfly Conservatory: Tropical Butterflies Alive in Winter!* Closes June 23

Kids and adults alike are mesmerized and delighted by the fluttering iridescent creatures that might hitch a ride on an arm or shoulder. Truly a hands-on learning experience, *The Butterfly Conservatory* has been a favorite of Museum visitors for eight years.

This exhibition is made possible, in part, through the generous support of JPMorgan Chase.

PEOPLE AT THE AMNH

Sandy Wright
Administrative Manager,
Visitor Services

D. FINNIN/AMNH

Like many 4-year-olds, Sandy Wright's nephew chattered away the first time she took him through the Museum; that is, until they reached the fossils on the fourth floor. Sandy smiles as she describes the silence that came over him as he stared up at the dinosaurs, his jaw gaping in awe. "It was so neat to tell him, 'This is where I work every day!'"

Sandy is as excited about her job today as she was seven years ago when she turned down an offer at an advertising agency just to interview at the Museum. The gamble paid off and she has been with Visitor Services ever since, researching special projects, tracking complaint letters, fielding donation requests and, more recently, helping select the IMAX films shown in the Museum's LeFrak Theater.

"I work with an outside consultant to find potential films, conduct research on film literature and box office reports, set up screenings, and finally select the films."

She is thrilled about the positive viewer feedback on the most recent choice, *Journey into Amazing Caves*, which Sandy describes as "an interesting blend of an adventure story with medical exploration."

Born in Springfield, Ohio, Sandy studied nutrition in Tallahassee, Florida, before moving to New York. She lives with her husband (whom she first met at age 12!) in the Hudson Valley, where she is learning to sail and applies her interest in food to cooking out with friends. "I really feel like I get the best of both worlds, working in the city by day and enjoying the tranquil scenery of the Hudson on the weekends."

Museum Events

AMERICAN MUSEUM of NATURAL HISTORY

www.amnh.org

A display of horse evolution in *Darwin*

Darwin

Through August 20, 2006

Featuring live animals, actual fossil specimens collected by Charles Darwin, and manuscripts, this magnificent exhibition offers visitors a comprehensive, engaging exploration of the life and times of Darwin, whose discoveries launched modern biological science.

The American Museum of Natural History gratefully acknowledges **The Howard Phipps Foundation** for its leadership support. Significant support for *Darwin* has also been provided by Chris and Sharon Davis, Bill and Leslie Miller, the Austin Hearst Foundation, Jack and Susan Rudin, and Rosalind P. Walter. Additional funding provided by the Carnegie Corporation of New York, Dr. Linda K. Jacobs, and the New York Community Trust–Wallace Special Projects Fund. *Darwin* is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with the Museum of Science, Boston; The Field Museum, Chicago; the Royal Ontario Museum, Toronto, Canada; and the Natural History Museum, London, England

The Butterfly Conservatory

Through June 23, 2006

A return engagement of this popular exhibition includes up to 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

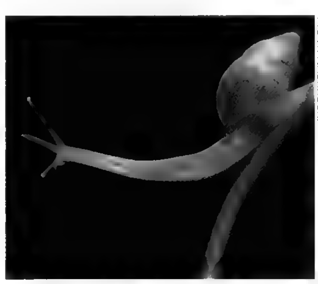
This exhibition is made possible, in part, through the generous support of JPMorgan Chase.

Voices from South of the Clouds

Through July 23, 2006

China's Yunnan Province is revealed through the eyes of the indigenous people, who use photography to chronicle their culture, environment, and daily life.

The exhibition is made possible by a generous grant from Eastman Kodak Company. The presentation of this exhibition at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.



PIOTR NASKRECKI

Land snail in *Vital Variety*

Vital Variety

Ongoing

Beautiful close-up photographs highlight the diversity of invertebrates.

LECTURES

Mark and Delia Owens: Secrets of the Savannah

Thursday, 6/1, 7:00 p.m.

Mark and Delia Owens dramatically reduced poaching of elephants in Zambia by offering villagers alternatives. A book signing follows.

The 1906 Earthquake

Tuesday, 6/13, 7:00 p.m.

Introduced by Edmond Mathez, AMNH, and led by Mary Lou Zobak, USGS, this compelling lecture addresses lessons learned and future directions in earthquake science and management.

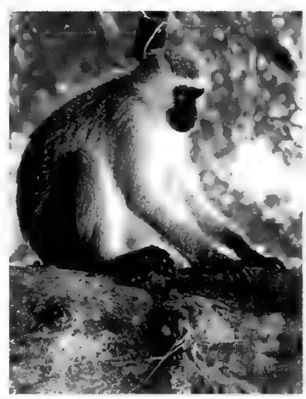


PHOTO COURTESY OF WILDLIFE-PICTURES

Kids can learn about the natural world at AMNH summer camps.

An Evening with Edward O. Wilson

Wednesday, 6/14, 7:00 p.m.

Two-time Pulitzer Prize winner Edward O. Wilson converses with Museum Provost Michael Novacek. A book signing follows.

Endless Forms Most Beautiful

Thursday, 6/22, 7:00 p.m.

Sean Carroll, University of Wisconsin-Madison, discusses a new view of the relationship between developmental and evolutionary biology.

FIELD TRIPS AND WORKSHOPS

Around Manhattan Island

Tuesday, 6/20, 6:00–9:00 p.m.

A three-hour cruise with geologist Sidney Horenstein.

South African Beading

Four Thursdays, 6/22–7/13

7:00–9:00 p.m.

Led by instructor Marsha Davis.

FAMILY AND CHILDREN'S PROGRAMS

Robots in Space III (Advanced)

Tuesday–Thursday, 6/6–8

4:00–5:30 p.m.

Hone your skills as an expert robot designer.

NEW! Cosmic Splat!

Saturday, 6/10

11:00–12:30 p.m. (Ages 4–5, each child with one adult)

1:30–3:00 p.m. (Ages 6–7, each child with one adult)

Explore the forces that drive the universe.

AMNH ADVENTURES: SUMMER CAMPS

Monkey Business: Primatology

Monday–Friday, 6/19–23

STARRY NIGHTS

Live Jazz

ROSE CENTER FOR EARTH AND SPACE

Friday, June 2

6:00 and 7:30 p.m.

Houston Person Quartet

The 7:30 p.m. set will be broadcast live on WBGO Jazz 88.3 FM.

Starry Nights is made possible, in part, by Fidelity Investments.

9:00 a.m.–4:00 p.m.
(For children entering grades 2 or 3)
Journey to rain forests, dry forests, and savannahs.

NEW! AMNH Sampler Camp
Monday–Wednesday, 6/26–28
9:00 a.m.–1:00 p.m.
(For children entering grade 1)
A day each of astrophysics, lizards, and oceans.

Ocean Adventures
Monday–Wednesday, 6/26–28
9:00 a.m.–3:00 p.m.
(For children entering grades 2 or 3)
From squid dissections to "fish tales," this camp is full of fun activities.

R. MICKENS/AMNH

In the Milstein Hall of Ocean Life

HUBBLE HERITAGE TEAM (AURA/STSCI/NASA)

Glowing gas surrounds a hot, massive star in our Milky Way galaxy.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
Nebulae
Tuesday, 6/6, 6:30–7:30 p.m.

This Just In...
June's Hot Topics
Tuesday, 6/20, 6:30–7:30 p.m.

Celestial Highlights
The Bear and the Lion
Tuesday, 6/27, 6:30–7:30 p.m.

HAYDEN PLANETARIUM SHOWS

Cosmic Collisions
Journey into deep space—well beyond the calm face of the night sky—to explore cosmic collisions, hypersonic impacts that drive the dynamic formation of our universe. Narrated by Robert Redford.

Cosmic Collisions was developed in collaboration with the Denver Museum of Nature & Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum.
Made possible through the generous support of CIT.
Cosmic Collisions was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division.

SonicVision
Fridays and Saturdays, 7:30 and 8:30 p.m.
Hypnotic visuals and rhythms take viewers on a ride through fantastical dreamspace.

SonicVision is made possible by generous sponsorship and technology support from Sun Microsystems, Inc.

AMNH

The Museum's spectacular new Space Show

LARGE-FORMAT FILMS
LeFrak IMAX Theater
Journey into Amazing Caves
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IMAX films at the Museum are made possible by Con Edison.

INFORMATION
Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION
Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.
All programs are subject to change.

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THE MUSEUM SHOPS

ENDPAPER

Stress and the City

By Robert M. Sapolsky

As part of my research, I study the physiology of wild baboons in the Serengeti, which is where I am now. I share my camp with a guy named Soirowua, a member of the local Masai.

The other morning, we were collecting firewood—not one of my favorite chores. I'm always anxious about stomping around in thickets with no visibility. At a particularly thick stretch, I balked. "Er, do you think it's a good idea to go in there?"

"Why not?" Soirowua answered, puzzled.

"Um, there may be buffalo in there."

That made his day. He chortled with delight at my wimpiness and plunged on in, emerging some time later with firewood.

That evening I found myself sulking about the incident, searching for some retort that would shore up my always fragile sense of manhood. "Okay," I thought, "so Soirowua's great with buffalo, but could he navigate the Forty-Second Street subway station? Could he score tickets to *The Lion King* on short notice?"

Ah, there you have it, the contrast between a highly urbanized culture and that of more traditional humanity. For nomadic pastoralists like Soirowua, most stress involves some physical challenge—disease, drought, hungry lions. For a New Yorker, stress takes the form of unprecedented population density, time-pressured, ambiguous social interactions, finding tickets to shows about lions.

With the two lifestyles pigeonholed and dichotomized, I feel a rant ready in the wings: how our Westernized way of life of chronic psychosocial stress sets us up for all sorts of maladies. . . .

There's just one problem with that explanation: Lots of people, including me, *love* New York and all its stressors. Plenty of New Yorkers have fled their warm, supportive, calm, safe small towns all over America to live in a closet-size apartment and spend subway time every day armpit-to-armpit with strangers.

What's up with that?

Well, some people probably don't actually like New York in the slightest—survival and mastery are what's pleasurable. They "do" New York for a year, before fleeing back to where they came from, adventure complete. They don't count in this analysis.

Then there are the folks whose pleasure is deconstructing the New Yorkiness out of the city, turning one little piece of it into an embedded village. Apparently, this has been a goal of some urbanites from the beginning. Çatalhöyük, in Turkey, is an early example of high-density living, but archaeological evidence suggests that Çatalhöyük less resembled a large town than a whole bunch of villages jammed together [*see "This Old House," by Ian Hodder, page 42*]. Even back then, city dwellers would be pleased when the guy with the falafel stand knew their name.

There are some people who enjoy the culture, variety, and so on of New York, but could do without the zillions of people. In college, I used to play a game with other New Yorkers. Imagine Manhattan is still a primordial forest, except for three functioning New York institutions, situated exactly where they are now. Which would you pick? And we'd happily imagine walking through a snow-filled forest, where this deer trail led to Lincoln Center, that one skirted a swamp en route to the Famous Ray's Pizza.

But for some people, merely *arriving* at Ray's defeats the whole purpose. For them, the idea is to rush to Ray's from Lincoln Center amid a rude, jostling crowd of people, all intent on getting in line ahead of you. The stress and tumult and social complexity are intrinsic to the pleasure.

The explanation for this makes sense the second it's stated—stress is not uniformly aversive. In fact, we all love certain kinds of stress.

Of course, when we are massively stressed for long periods, we lose the capacity for pleasure. We feel depressed, anxious, exhausted, angry. The neurochemical explanation involves a neurotransmitter in the brain called dopamine, which plays a key role in feeling pleasure (or, more precisely, in feeling the anticipation of pleasure). Sustained major stress depletes those pathways of dopamine.

But remarkably, mild, transient stress *increases* the release of dopamine. There's just a narrow window for this phenomenon. Experience stress that's mild and chronic instead of mild and transient and there's no dopamine release. Ditto with massive, transient stress.

And what do we call mild, transient stress? Stimulation. We don't seek a life without stress. We love the right amount of it, pay good money for it. That suggests that people who love New York because of its stressors are the ones whose New York experience involves frequent and intermittent refuge from the din and roar. The essence of pleasure, including stressful pleasures, is intermittency. City planners, take note.

Robert M. Sapolsky is a professor of biological sciences and neurology at Stanford University. He spent much of his childhood inside the American Museum of Natural History, where he wanted to live in one of the African dioramas.

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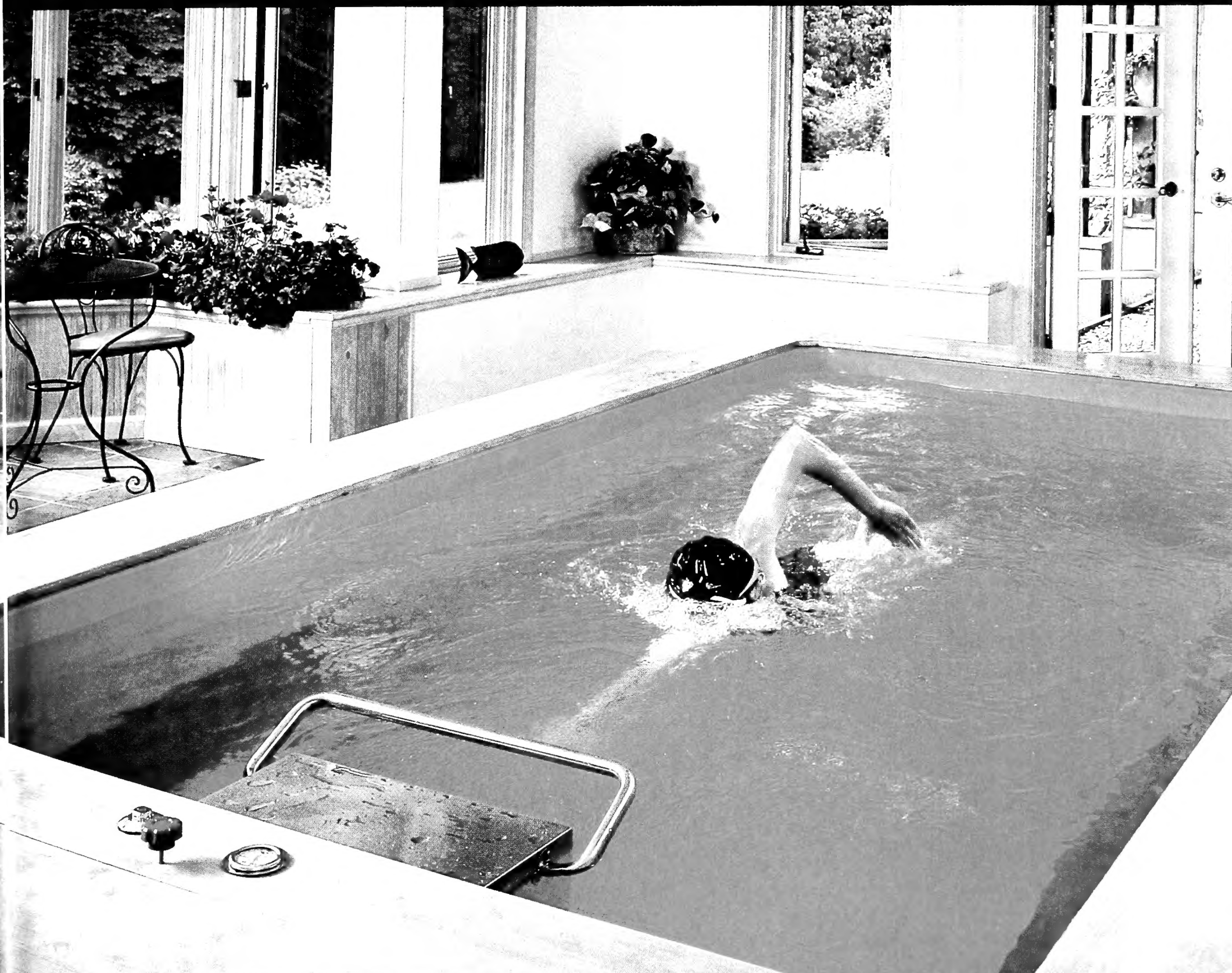

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